SECOND PARTIAL REPORT
ON THE
ARTIFICIAL PRODUCTION OF PRECIPITATION

CB

CUMULIFORM CLOUDS, OHIO

1948

RESEARCH PAPER NO. 31

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SECOND PARTIAL REPORT ON THE ARTIFICIAL PRODUCTION OF PRECIPITATION

Cumuliform Clouds—Ohio, 1948

By

RICHARD D. COONS, EARL L. JONES, and ROSS GUNN

SUMMARY

This second phase of the Cloud Physics Project was carried on in the vicinity of Wilmington, Ohio, during the spring and summer of 1948. The organization, facilities, and general mode of attack were the same as those used in the first phase of the project [1] and described in the next section of this report. In this second phase of the study, the basic objective was to determine in definite quantitative terms the practical limits and economic importance of cloud modification processes in producing precipitation from cumuliform clouds.

On most of the seeding operations the following observations were made in flight in and near the clouds: (*a*) Height of the base and top; (*b*) relative humidity above and below; (*c*) temperatures inside and outside both at the base and the top; (*d*) the compositon before and after seeding; (*e*) the optical characteristics; (*f*) the extent of the seeded area; (*g*) the location, extent and character of precipitation; (*h*) the behavior of unseeded clouds in the vicinity. In addition to these data, the radar and the rain gages of the surface network provided invaluable information. In general, dry ice was seeded at the rate of about 8 pounds per mile. Sometimes additional amounts of from 20 to 40 pounds were suddenly dropped into a cloud for special study. When water was used, it was usually at the rate of about 50 gallons per mile, although occasionally much lower rates were used. The particular kind of persistent nuclei employed in some of the air experiments was one of a large number of chemical agents that had been found effective in producing cloud modification effects when dispersed in the vapor form. Lead oxide was used on the full-scale experiments because of its convenience, but potassium iodide is equally effective.

The crucial difficulty in dealing with the modification of convective type clouds is to separate the natural effects from those artificially induced. As in the earlier work, the radar-controlled aircraft movements were carefully coordinated, and the radar indications of precipitation were found to be a prime necessity in the proper evaluation of the results. Table 1 gives a detailed analysis of the respective seeding missions and enumerates the results.

Clouds investigated were divided into two categories, supercooled and nonsupercooled, and further subdivided depending on whether the cloud, was seeded with dry ice or water. Tables 2 through 4 summarize the results as related to rain production and cloud dissipation for 79 clouds, collected on 30 operating days between March 15, 1948, and September 8, 1948. In Table 2 it may be seen that although precipitation fell from a total of 18 clouds when there had been no precipitation falling before the seedings, there were only 5 clouds that produced precipitation without the occurrence of natural rain within 30 miles. Even for these cases, showers occurred naturally within 40 to 60 miles. The table also shows that there were 16 clouds from which rain fell to the ground after seeding, but 11 of these were producing rain naturally at the time of seeding. Furthermore, there were natural showers occurring within 30 miles of each of the 16 clouds. Precipitation resulting from seeding operations, when rain was not falling from the clouds prior to their treatment, was trivial in amount. In fact, not more than a trace of rain was recorded following treatments, with the exception of an estimated 0.2 inch which fell on June 28 from a seeded cloud.

During the course of operations, it became apparent that the most obvious effect of seeding in cumulus clouds was the initiation of rapid dissipation. Results listed in table 3 show that of 10 cases of complete cloud dissipation which followed treatment, there were only 4 clouds that were observed to be building at the time of seeding. Of the 9 clouds that grew vertically after seeding, all but one were building before the seeding, and there was no noticeable change in the rate of growth after the seeding operation. Not included in the table were: one case in which a dissipating

[1] These were described in the following publications entitled "First Partial Report on the Artificial Production of Precipitation, Stratiform Clouds, Ohio 1948," by R. D. Coons, R. C. Gentry, and Ross Gunn—(a) *Bulletin of the American Meteorological Society*, vol. 29, No. 5, May 1948, pp. 266–269; and (b) *U. S. Weather Bureau Research Paper No. 30*, August 1948.

Table 1.—*Detailed Analysis of 79 Seeding Missions of Cumuliform Clouds*

Date [1]	Base of clouds (ft.)	Top of seeded cloud (ft.)	Temperature vicinity of bases (°C)	Temperature vicinity of tops (°C)	Freezing level of the environment (ft.)	Seeding altitude (ft.)	Were clouds supercooled?	Seeding nuclei	Rate of seeding [2]: Pounds per mile (CO_2)	Rate of seeding [2]: Pounds through photo hatch (granulated CO_2)	Rate of seeding [2]: Gallons per mile (H_2O)	Were any results observed?	Was there partial dissipation only?	Was there complete dissipation?	Was there only building after seeding?	Status of cloud (B=building; D=dissipating; S=stagnant)	Was there cloud echo before seeding?	Was there cloud echo after seeding?	Was light rain falling before or after seeding but with no radar echo?	Did precipitation fall from cloud?	Amount of rain	Were natural showers within 30 miles?
3-16-48	4,500	15,500	7.0	−15.0	7,800	15,000	Yes?	CO_2	18			No	No	No	No	S	No	No	No	No	None	Yes.
3-16-48	4,500	17,250	7.0	−19.0	7,800	17,280	Yes?	CO_2	17			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
3-31-48	5,500	18,500	7.0	−23.0	10,300	17,000	Yes	CO_2	20			Yes	Yes	No	No	B	No	Yes	No	Yes	T?	Yes.
3-31-48	5,500	18,500	7.0	−23.0	10,300	18,000	Yes	CO_2	20			Yes	Yes	No	No	S	No	No	No	No	None	Yes.
3-31-48	5,500	17,000	7.0	−20.0	10,300	17,000	Yes	CO_2	20			Yes	Yes	No?	No	B	No	No	No	No	None	Yes.
4-27-48	5,500	15,000	11.0	−8.0	11,700	15,000	Yes	CO_2	2			Yes	No	No	Yes	B	No	No	No	No	None	Yes.
4-27-48	5,500	13,000	11.0	−3.0	11,700	14,000	Yes?	CO_2	3			Yes	No	No	Yes	B	No	Yes	No	Yes	Virga?	Yes.
4-27-48	5,500	13,000	11.0	−3.0	11,700	15,000	Yes?	CO_2		40		Yes	No	No	Yes	B	No	No	No	No	None	Yes.
4-27-48	5,500	13,000	11.0	−3.0	11,700	(3)	Yes?	CO_2		60		Yes	No	No	Yes	B	No	No	No	No	None	Yes.
5-11-48	5,000	14,000	15.0	−3.0	12,500	14,500	No?	CO_2	6			Yes	Yes	No	No	D	No	No	No	No	None	Yes.
5-11-48	5,000	12,500	15.0	0.0	12,500	13,000	No	CO_2		30		Yes	Yes	No	No	D	No	No	No	No	None	Yes.
5-11-48	5,000	12,500	15.0	0.0	12,500	12,000	No	CO_2	26			Yes	No	No	Yes	D?	No	No	No	No	None	Yes.
5-17-48	4,400	11,500	8.0	−5.0	7,750	11,000	Yes?	CO_2	8	20		Yes	Yes	No	No	B	No	Yes	No	Yes	Virga	No.
5-17-48	4,800	12,500	8.0	−7.0	7,750	12,000	Yes	CO_2	8	20		Yes	Yes	No	No	B	No	Yes	No	Yes	Virga	No.
5-18-48	5,200	15,150	8.0	−9.0	8,250	14,640	Yes	CO_2	15			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
5-18-48	5,200	15,000	8.0	−9.0	8,250	15,590	Yes	CO_2	6	20		Yes	Yes	No	No	B	Yes	Yes	No	Yes	Unknown	Yes.
5-18-48	5,200	15,000	8.0	−9.0	8,250	15,000	Yes	CO_2	7	30		Yes	Yes	No	No	B	Yes	Yes	No	Yes	Unknown	Yes.
5-21-48	4,900	17,000	16.0	−8.0	12,800	17,300	Yes	CO_2	4			Yes	Yes	No	No	B	No	No	No	No	None	No.
5-21-48	4,900	18,000	16.0	−10.0	12,800	18,000	Yes	CO_2	5			Yes	Yes	No	No	B	No	No	No	No	None	No.
5-21-48	4,900	18,700	16.0	−11.0	12,800	18,500	No	CO_2	6			Yes	No	No	Yes	B	No	No	No	No	None	No.
6-15-48	5,100	19,000	16.0	−12.0	12,800	21,890	Yes	CO_2	7			Yes	Yes	No	No	B	No	No	A?	Yes	Virga?	Yes.
6-15-48	5,100	20,000	16.0	−14.0	12,800	22,000	Yes	CO_2 [4]	6	20	1	Yes	Yes	No	No	B	No	No	A?	Yes	Virga?	Yes.
6-18-48	5,000	22,000	17.0	−14.0	14,400	21,000	Yes	CO_2 [4]	4		1	Yes	Yes	No	No	B	No	Yes	No	Yes	Virga?	Yes.
6-18-48	5,000	23,000	17.0	−18.0	14,400	21,800	Yes	CO_2 [4]	4		1	Yes	Yes	No	No	B	No?	Yes?	No	Yes	Unknown	Yes.
6-22-48	5,000	20,000	20.0	−6.0	16,400	19,600	Yes	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.
6-22-48	5,000	20,000	20.0	−6.0	16,400	19,500	Yes	H_2O			1	Yes	Yes	No	No	B	Yes	Yes	No	Yes	Virga?	Yes.
6-22-48	5,000	20,100	20.0	−6.0	16,400	20,100	Yes	CO_2	3			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
6-22-48	5,000	18,000	20.0	−4.0	16,400	18,330	Yes	H_2O			1	Yes	No	Yes	No	B	No	No	No	No	None	Yes.
6-24-48	5,200	19,000	18.0	−7.0	14,000	19,940	Yes?	CO_2	4			Yes	No	Yes	No	B	Yes	Yes	No	Yes	Unknown	Yes.
6-24-48	5,200	18,000	18.0	−6.0	14,000	18,000	Yes	CO_2	4			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
6-28-48	6,000	18,500	16.0	−8.0	13,600	18,500	Yes	CO_2	7			Yes	Yes	No	No	B	No	Yes	No	Yes	0.22	Yes.
6-29-48	3,500	19,000	18.0	−8.0	13,400	20,000	Yes?	CO_2	15			Yes	Yes	No	No	B	Yes	Yes	No	Yes	Virga	Yes.
6-30-48	3,500	18,000	18.0	−10.0	12,400	16,500	Yes	CO_2	12			Yes	Yes	No	No	B	No	Yes	No	Yes	T	Yes.
7-07-48	5,300	8,000	13.0	6.0	15,200	7,940	No	H_2O			50	Yes	Yes	No	No	B	No	No	No	No	None	No.
7-07-48	5,300	8,900	13.0	8.0	15,200	8,900	No	H_2O			50	Yes	Yes	No	No	B	No	No	No	No	None	No.
7-09-48	5,200	11,900	18.0	4.0	14,200	11,500	No	H_2O			50	Yes	Yes	No	No	S	(5)	(5)	No	No	None	No.
7-09-48	5,200	11,900	18.0	4.0	14,200	11,500	No?	CO_2 [4]	15		50	Yes	Yes	No	No	S	(5)	(5)	(5)	Yes	Virga	No.
7-09-48	5,200	24,500	18.0	−23.0	14,200	23,800	Yes	CO_2 [4]	12		50	Yes	Yes	No	No	B	(5)	(5)	(5)	Yes?	Virga	Yes.
7-12-48	3,800	19,500	20.0	−8.0	15,500	19,500	Yes	CO_2	8			Yes	Yes	No	No	B	Yes	Yes	No	Yes	0.11	Yes.
7-12-48	3,800	20,000	20.0	−9.0	15,500	20,000	Yes	CO_2	8			Yes	Yes	No	No	B	Yes	Yes	No	Yes	0.11	Yes.
7-12-48	3,800	7,000	20.0	14.0	15,500	7,000	No	H_2O			50	No	No	No	No	S	No	No	No	No	None	Yes.
7-13-48	5,000	13,000	17.0	3.0	14,600	12,700	No	H_2O			50	Yes	No	Yes	No	B	No	No	No	No	None	Yes.
7-13-48	5,000	13,300	17.0	2.0	14,600	13,000	No?	H_2O			50	Yes	Yes	No	No	B	No	No	A	Yes	Virga	Yes.
7-13-48	5,000	17,000	17.0	−4.0	14,600	15,000	Yes	CO_2	15			Yes	Yes	No	No	B	No	Yes	No	Yes	T	Yes.
7-16-48	4,500	13,000	19.0	5.0	15,800	10,000	No?	CO_2	5			Yes	Yes	No	No	B	Yes	Yes	No	Yes	T	Yes.
7-16-48	4,500	15,000	19.0	1.0	15,800	11,020	No?	CO_2	5			Yes	Yes	No	No	B	Yes	Yes	No	Yes	T?	Yes.
7-19-48	4,000	13,700	18.0	1.0	14,000	13,460	No	H_2O			1	Yes	No	Yes	No	D	No	No	No	No	None	Yes.
7-19-48	4,000	16,500	18.0	−2.0	14,000	15,720	Yes?	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.
7-27-48	4,400	10,000	17.0	7.0	14,200	10,000	No	H_2O			1	Yes	No	Yes	No	D	No	No	No	No	None	No.
7-27-48	4,400	10,000	17.0	7.0	14,200	10,000	No	None (flew through top)				Yes	No	Yes	No	D	No	No	No	No	None	No.
7-27-48	4,400	12,300	17.0	3.0	14,200	12,700	No	CO_2	4			Yes	No	Yes	No	D	No	No	No	No	None	No.
7-30-48	4,550	13,200	20.0	4.0	16,500	13,500	No	CO_2	7			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
7-30-48	3,700	14,900	24.0	2.0	16,500	15,000	No	CO_2	6			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
7-30-48	3,500	16,500	25.0	0.0	16,500	16,500	No?	CO_2	6			Yes	Yes	No	No	B	Yes	Yes	No	Yes	T?	Yes.
8-05-48	4,000	12,980	13.0	−4.0	10,200	12,980	Yes	CO_2	6			Yes	Yes	No	No	B	No	Yes	No	Yes	Virga	Yes.
8-05-48	4,500	13,080	12.0	−4.0	10,200	13,080	Yes	CO_2		10		Yes	Yes	No	No	B	No	No	No	No	None	Yes.
8-05-48	4,500	13,040	12.0	−4.0	10,200	12,900	Yes	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.

8-11-48	3,000	13,620	17.0	0.0	13,620	13,620	No	CO_2	8			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
8-11-48[6]	3,000	11,830	17.0	3.0	13,620	11,830	No	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.
	3,000	11,830	17.0	3.0	13,620	11,830	No?	H_2O			1	Yes	Yes	No	No	B	Yes	Yes	No	Yes	Virga	Yes.
	3,000	11,830	17.0	3.0	13,620	11,830	No	H_2O			1	Yes	No	No	Yes	B	No	No	No	No	None	Yes.
	3,000	11,830	17.0	3.0	13,620	11,830	No	H_2O			1	Yes	No	No	Yes	B	No	No	No	No	None	Yes.
8-11-48	3,000	11,000	17.0	5.0	13,620	10,000	No	PbO (vaporized PbO)				Yes	Yes	No	No	B?	No	No	No?	No?	None?	No.
8-13-48	6,000	15,000	14.0	−2.0	13,700	15,400	Yes?	CO_2	6			Yes	No	Yes	No	S	No	No	No?	No?	None?	No.
8-13-48	6,000	15,300	14.0	−2.0	13,700	15,300	Yes	CO_2	5			Yes	No	Yes	No	S	No	No	No	No	None	Yes.
8-13-48	6,000	14,000	14.0	−1.0	13,700	14,000	Yes	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	No.
8-13-48	6,000	14,000	14.0	−1.0	13,700	14,000	Yes?	CO_2		40		Yes	No	Yes	No	S	No	No	No	No	None	No.
8-17-48	6,000	15,300	12.0	−5.0	11,800	15,000	Yes	CO_2	6	20		Yes	Yes	No	No	B	No	No	No	No	None	No.
8-17-48	6,000	15,000	12.0	−5.0	11,800	14,700	Yes	CO_2	6	20		Yes	Yes	No	No	B	No	Yes	No	Yes	Virga	No.
8-17-48	6,300	16,000	11.0	−6.0	11,800	15,600	Yes	CO_2	6	40		Yes	Yes	No	No	B	No	No	A	Yes	Virga	No.
8-18-48	4,700	16,000	13.0	−6.0	12,200	15,000	Yes	CO_2	4			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
8-18-48	5,000	15,000	13.0	−5.0	12,200	15,000?	Yes	CO_2	5	20		Yes	No	Yes	No	B	No	No	No	No	None	Yes.
8-18-48	5,000	17,000	13.0	−8.0	12,200	17,000	Yes?	CO_2	4	20		Yes	Yes	No	No	D	No	No	No	No	None	Yes.
8-18-48	4,900	14,500	13.0	−4.0	12,200	14,000	Yes	CO_2	7			Yes	Yes	No	No	D	No	No	No	No	None	Yes.
8-18-48	4,500	14,000	15.0	−3.0	12,200	13,300	Yes	PbO (vaporized PbO)				Yes	Yes	No	No	D	No	No	No	No	None	Yes.
8-30-48	7,200	16,700	14.0	−5.0	13,800	16,500	Yes	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.
8-30-48	5,500	16,700	17.0	−5.0	13,800	16,500	Yes	H_2O			1	Yes	No	No	Yes	B	No	Yes	No	Yes	Unknown	Yes.
9-07-48	2,700	19,200	21.0	−8.0	14,100	17,500	Yes	None (flew through top)				Yes	Yes	No	No	B	Yes	Yes	No	Yes	Unknown	Yes.
9-07-48	3,000	17,300	20.0	−5.0	14,100	17,500	Yes	CO_2	4			Yes	Yes	No	No	D	Yes	Yes	No	Yes	T?	Yes.
9-07-48	3,100	17,500	20.0	−5.0	14,100	17,500	Yes	CO_2	4			Yes	Yes	No	No	B	Yes	Yes	No	Yes	Unknown	Yes.
9-07-48	4,100	16,000	17.0	−2.0	14,100	16,000	Yes	CO_2	4			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
9-08-48	6,000	16,800	13.0	−2.0	14,000	16,700	Yes	CO_2	5			Yes	Yes	No	No	B	No	No	No	No	None	Yes.
9-08-48	5,600	17,800	14.0	−3.0	14,000	18,000	Yes	H_2O			1	Yes	Yes	No	No	B	No	No	No	No	None	Yes.
9-08-48	5,000	19,200	16.0	−6.0	14,000	17,000	Yes	None (flew through top)				Yes	Yes	No	No	B	No	No	No	No	None	Yes.

[1] Each date line represents different clouds.
[2] Rates averaged when more than one drop in same cloud.
[3] Unknown.
[4] Water was used also.
[5] Unknown; radar inoperative.
[6] Average tops.

TABLE 2.—*Summary of results of seeding 79 clouds, as related to rain production*

Type of cloud	Number of cases	Light rain fell from seeded cloud	Light rain after seeding only	Light rain after seeding only and rain reached ground	Light rain after seeding only and no showers within 30 miles	No rain after seeding but showers within 30 miles
			USING DRY ICE			
Supercooled	46	23	15	4	4	18
Nonsupercooled	12	[1] 4	1	0	1	6
			USING WATER			
Supercooled	9	2	1	1	0	6
Nonsupercooled	12	[1] 2	1	0	0	6
Total (for all seedings)	79	31	18	5	5	36

[1] All clouds in this category were approximately at the freezing level and might have been supercooled even though no icing was noted by the seeding aircraft.

TABLE 3.—*Summary of results of seeding 79 clouds, as related to dissipation*

Type of cloud	Number of cases	Partial dissipation	Complete dissipation	Some building after seeding	Partial dissipation of building clouds	Complete dissipation of building clouds	Building after seeding of building clouds
				USING DRY ICE			
Supercooled	46	36	5	4	32	2	4
Nonsupercooled	12	9	1	2	6	0	1
				USING WATER			
Supercooled	9	7	1	1	7	1	1
Nonsupercooled	12	6	3	2	5	1	2
Total (for all seedings)	79	58	10	9	50	4	8

nonsupercooled cloud dissipated completely and two cases in which building supercooled clouds partially dissipated after a plane was flown through them without seeding; and two cases of partial dissipation that were observed after seeding with persistent nuclei (one a building, nonsupercooled cloud, the other a dissipating supercooled cloud).

Table 4 shows that when either or both towers of 18 multi-towered clouds were seeded, dissipation of the seeded portion always followed whether or not the cloud was building at the time of seeding. In most clouds of which only one tower was seeded, the second tower continued to build.

TABLE 4.—*Summary of results of seeding 18 multi-towered clouds, as related to dissipation*

Clouds seeded	One tower seeded	Seeded tower dissipated	Unseeded tower continued to build	Cloud building at time of seeding	Both towers seeded consecutively	Both towers dissipated	Cloud building at time of seeding	Cloud stagnant at time of seeding
All cases (both H_2O and CO_2 seedings)	10	10	9	10	8	8	7	1

This dissipation appeared to be nearly independent of supercooling or of the particular agent employed. Its occurrence was consistent with the idea that convective clouds often have lapse rates steeper than the moist adiabatic as a result of mixing and entrainment between such clouds and the environment [1, 2]. A downward movement initiated by dry ice, large numbers of ice crystals, water, or other means (aircraft flying vertically upward through the cloud have been employed successfully) might easily cause an appreciable mass of air to become colder than the surrounding clouds, and thus induce further downward motion. A similar explanation has been advanced by Byers and Braham [3] for the formation of the thunderstorm downdraft.

The experiments showed that the artificial modification of cumuliform clouds is of doubtful economic importance for the production of rain. Dissipation rather than new development was the general rule. There is no indication that seeding will initiate self-propagating storms, and therefore, the only precipitation that can be extracted from a cloud is that contained within the cloud itself. The methods are certainly not promising for the relief of drought.

The third phase of the Cloud Physics Project, now under way, will concern artificial modification of orographic type clouds and also, of clouds in different climatic areas.

SECOND PHASE OF CLOUD PHYSICS PROJECT

BASIC OBJECTIVE

The basic objective of the Cloud Physics Project is to determine in definite quantitative terms the practical limits and general utility of cloud modification processes in producing or suppressing precipitation and increasing the visibility from flying aircraft. In order that the effects of the induced modifications may be clearly separated from those occurring naturally, a closely coordinated attack using all available measuring facilities was adopted.

PARTICIPATION OF COOPERATING AGENCIES

The Cloud Physics Project was established as a result of recommendations made by the Meteorological Sub-committee of the Air Coordinating Committee on August 19, 1947. The Project is a cooperative effort of the U. S. Air Force, the National Advisory Committee for Aeronautics, and the U. S. Weather Bureau.

The Air Force provided, operated, and maintained at Wilmington, Ohio, a number of airplanes for the evaluation of cloud modification techniques.

High-powered ground radar equipment was also provided, together with office space and necessary ground facilities.

The National Advisory Committee for Aeronautics cooperated by assigning from time to time, a highly experienced cloud analysis team and their especially equipped airplane.

The U. S. Weather Bureau set up, operated, and maintained a surface and upper-air network of stations to observe the micrometeorology of the operating area. The technical planning and scientific leadership of the Project were provided by the Physical Research Division of the Weather Bureau.

The U. S. Navy provided on loan much of the equipment installed in the meteorological network.

Various individuals from Universities and other interested agencies acted in an advisory capacity.

FACILITIES

The facilities in the vicinity of Wilmington, Ohio, used by the Cloud Physics Project have been described in the "First Partial Report on the Artificial Production of Precipitation, Stratiform Clouds, Ohio, 1948" (U. S. Weather Bureau *Research Paper No. 30*). However, to reacquaint the reader with them, and especially with their utilization on this project, a short discussion is given.

Near Jamestown, Ohio, is situated the AN/CPS-6 (V-Beam) Radar, which is the focal point of all cloud seeding operations. Not only is this radar desirable for controlling and indicating the path of each of the aircraft involved in the investigation but it also indicates the presence of precipitation areas whether they be formed naturally or as a result of seeding. The scope presentations of this radar are photographed automatically at 10-second intervals. On each frame of film a data card and a clock are recorded to identify the picture properly. There is at the same location an AN/TPS-10 height-finding radar, the scopes of which are also photographed.

To the south of the radar site is a rectangularly-shaped area, measuring 8 by 20 miles, within which are spaced 55 recording weather stations. Each of these stations records rainfall, wind velocity, temperature, pressure, and relative humidity on charts which are removed each day. Ferguson weighing-type rain gages are used at each of these locations, somewhat modified to increase the accuracy and sensitivity of rainfall rate measurements. They utilize throats which give catches 2½ times larger than the normal ones, and they are geared for one revolution of the clock drum every 6 hours. In addition to the rectangular network, there are in the immediate vicinity a number of other recording rain gages. Within the rectangular network, there are also two rawinsonde stations which provide, as required, necessary information regarding the temperature, pressure, moisture, and winds of the upper atmosphere.

Clinton County Air Force Base is conveniently located with respect to the other facilities. Based there are a number of specially instrumented Ari Force planes which participate in seeding missions. A short description of the responsibilities of each of the participating aircraft is given in order to outline the plan of operation.

A B-17 with a calibrated seeding conveyor drops dry ice into the cloud at such locations and on such headings as directed through radio contact by the radar controller at the Jamestown site. The controller attempts to plan the seeding in such an area that its maximum effects will be noted and measured over the surface network. The dry ice used is crushed and separated so that it consists of particles no larger than ⅜ inch in effective diameter. Whenever possible, the rates of seeding are varied on successive runs in order to determine the effects of over- or under-seeding. In general, however, a minimum amount of dry ice is dropped so that over-seeding will not result. The seeding conveyor is carefully calibrated, and indicators of its periods and rates of operation are photographed from remote reading instruments installed in a photo panel along with indicators of other important parameters such as temperature, pressure altitude, and absolute altitude. Also installed in the B-17 is an AN/APS-10 lightweight radar, which is used to indicate the presence of light precipitation areas. In addition, photographs of the seeding operation are taken with still and motion-picture cameras from various points within this plane. Upon completing a seeding run, the plane circles the area of seeding, photographing and observing any results.

Water is dispersed into clouds by two different systems. First, a P-61 with two wing tanks, each having a capacity of about 165 gallons, is used. Each of the tanks is emptied in about 2 minutes through its own 2-inch solenoid valve when the P-61 is flying at about 150 miles per hour. This slow air speed was chosen in order to minimize the break-up of water droplets due to the rapid air flow. With both tanks open, the rate of water dispersal is between 50 and 60 gallons per mile. In the second system, water is pumped through a number of small orifices of a sprayer attachment located on the rear of the tail of a B-17. The rate of dispersal is about 1 gallon per mile. Droplets formed by this method are quite small, probably of the order of ½ millimeter in diameter, while those formed by the first method are estimated to be somewhat larger.

A high-altitude photo plane is positioned by the controller above the seeder at the start of the seeding run. This plane secures oblique pictures of the treated clouds by flying in a circle of about 5 miles radius about the seeded area. Clocks and data cards are included in the field of view of the cameras in the planes, so that the pictures secured can be easily identified and coordinated. Paths of the planes participating in the missions are recorded on the photographs of the ground radar scopes. From these photos it is possible to deter-

mine the exact location of any plane at any instant, since the planes are easily identified by special radar-operated beacon codes.

Several other aircraft participate in these flights in order to determine the structure of the cloud before and after seeding and to investigate the seeded areas and any precipitation falling from them. These planes, also controlled from the ground radar, fly above, within, and beneath the cloud, making observations and taking pictures of all interesting phenomena. All such reports are transmitted by radio and recorded on wire and disc recorders located both in the B–17 and on the ground.

To conduct inner cloud studies, a specially instrumented hot-wing B–25 provided by the Flight Propulsion Research Laboratory of the N. A. C. A. in Cleveland, is used on occasion.

DESIGN OF THE EXPERIMENT

Each cloud seeding mission is so designed that the information gained from the sources mentioned above is utilized to best advantage. Usually, seeding operations are performed in a cloud area which, moving with the upper winds, will pass over the network of recording stations within 15 to 30 minutes. The path of the seeded area can be traced from aircraft reports and the radar tracks of the various aircraft which follow it. Results of the seeding can be noted from observations taken from several points of vantage; namely, from the radar which indicates any resulting precipitation, by observers flying in airplanes above the cloud who note changes in cloud structure, by other observers flying in planes beneath the cloud who detect and note precipitation of very light intensity which is not detected by the radar, and by visual observers located on the ground who observe the presence of precipitation reaching the ground and any changes in the base of the cloud deck.

On most of the operations the following quantities are determined in flight: Height of base and top of seeded cloud decks, relative humidity above and below, temperatures inside and outside the clouds, lapse rates, optical characteristics, and extent and character of the precipitation. Also, an attempt is made to determine if precipitation reached the ground. The character of the data obtained may be best understood by considering a few examples of particular seeding missions.

EXAMPLES OF SEEDING MISSIONS

In determining the results of cloud seeding a close coordination of the various sources of information must be attained. Because of the nature of cumulus clouds, coordination by the use of radar is not only helpful but absolutely essential if definite quantitative values are to be obtained. Three representative examples of the use of radar in evaluating the various sources of information available from cloud seeding missions are described below. The first, the mission for June 30, 1948, illustrates a case in which a small shower that resulted from the seeding was differentiated from other showers that occurred almost simultaneously within 5 miles. In the second example, on May 17, 1948, a radar echo and accompanying shower resulted from seeding, and there were no other showers indicated by the radar scope within 50 miles. The last example is that of July 30, 1948. In this case, part of the cloud that was seeded already showed an echo indicating that precipitation had already started or was imminent. The part of the cloud that was seeded did not precipitate; however, observers underneath the cloud reported rain, which, as a result of the detailed analysis procedure, was attributed to the portion of the cloud that showed as an echo previous to the seeding.

Seeding of June 30, 1948—At the time of the first seeding, at 1415 E. S. T., the only cloud echoes that were on the radar scope were approximately 50 to 60 miles to the southeast of the area of operations (fig. 1). Several showers, however, had occurred over the Cloud Physics surface network between 1235 E. S. T. and 1325 E. S. T. A few widely scattered rain showers occurred again at about 1800 E. S. T. (fig. 2).

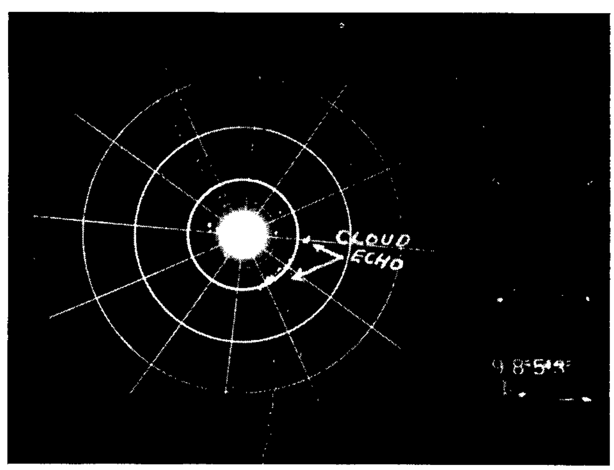


FIGURE 1.—June 30, 1948. 1415 E. S. T. Photograph of radar scope at time of first seeding, showing distant cloud echoes.

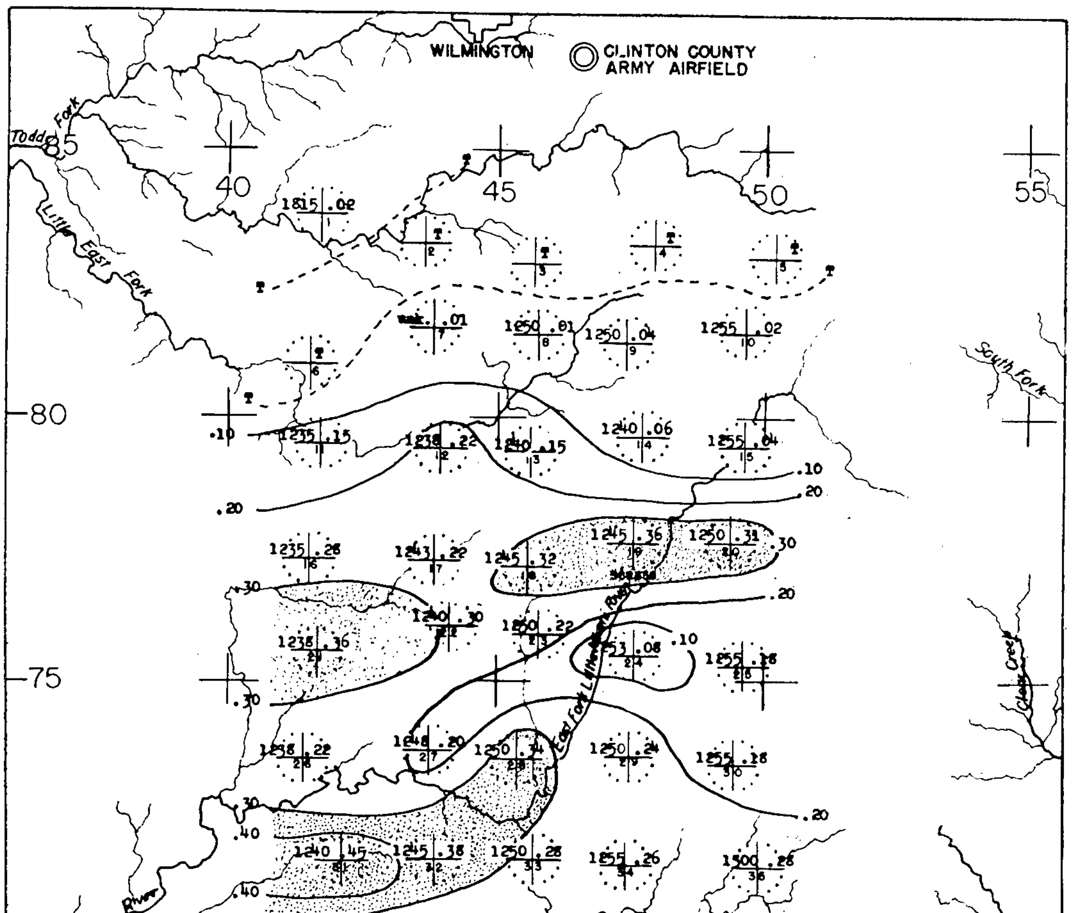


FIGURE 2.—Map showing times of beginning of precipitation and 10-hour totals for period ending at 2000 E.S.T. June 30, 1948 for 55 stations of surface network in the Wilmington area. (Precipitation in hundredths of inches.)

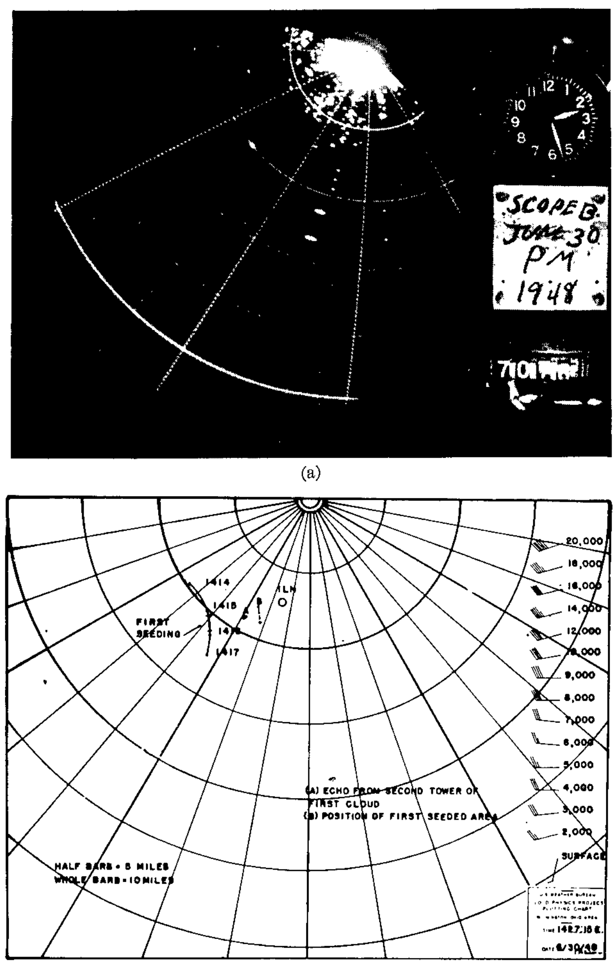
In picking the particular cloud for seeding, a consideration of whether the cloud was supercooled and the possibility of its passing over a surface rain gage were taken into account. Since this cloud met the criteria, it was chosen and was seeded three times. It had two pronounced towers, one seeded on the first run, the other on the second and third runs. The cloud ranged in thickness from 11,900 feet to 14,500 feet, with about 4,000 to 5,000 feet of supercooled water droplets. The freezing level of the environment in the vicinity of the cloud was near 12,400 feet mean sea level. The first seeding run was into the top of the cloud, which was building at the time, and from ⅛ to ¾ inch of clear ice accumulated on the aircraft. The second and third runs were made from above the cloud, which was observed to be stagnant each time.

The geographic orientation of the cloud, which was very important in the analysis of the results, was recorded by visual observation to be northeast-southwest in direction. Positions of the radar echoes and known positions of the seeded areas verified that this orientation was approximately correct. In the final analysis, another cloud a few miles southwest of the seeded one figured prominently.

Since the same portion of the cloud was seeded on the second and third runs, the movement of the seeded areas could be calculated by dividing the distance between the second and third seeded positions, as indicated by the seeding aircraft's position on the radar scope, by the time that elapsed between the two runs. This calculated velocity agreed very closely with observed winds aloft from 2,000 to 9,000 feet mean sea level, observed approximately 30 minutes before the first seeding within 15 miles of the seeded area. The direction of movement was also checked with the movement of echoes on the radar scope. Furthermore, visual observations of landmarks by the observers in the seeding aircraft made as the cloud passed over Clinton County Air Force Base (ILN) were very helpful in verifying the path of the seeded cloud.

Dry ice was dropped into the cloud at the rate of 10 to 15 pounds per mile. Observers in the seeding aircraft reported light to moderate turbulence in the cloud on the first run, but none was encountered above the cloud on the last two runs. Observers in the low observation plane reported the base of the seeded cloud to be dark gray in color at the time of the first seeding. When the plane was flown in a wide circle of the seeded area a short time later, they reported that other clouds in the area had bases of similar appearance, but no rain was observed in the area of operations prior to the first seeding run. Only a small amount of moisture collected on the plane when a run through the base of the seeded cloud was made before the first seeding.

The northeast portion of the seeded cloud passed over the Air Force Base about 1434 E. S. T. The weather station reported a special observation of light rain at 1435 E. S. T., which probably was the result of rain falling from the seeded portion of the cloud (figs. 5 (a) and 5 (b)). (Note: The vertical line on the radar scope pictures is always the 180-degree azimuth line, regardless of the orientation of the scope.) Assuming that the echo on the radar scope from the seeded cloud was from a portion near the freezing level, and considering the variation of the winds aloft, one would expect the rain to have reached the ground at some point west-northwest of the echo position. Since the echo from the second tower was located southwest of the airbase at the time the first rain was reported (figs. 5 (a) and 5 (b)), the aforementioned conditions would remove any possibility of rain from that portion of the cloud reaching the ground at a point east of its radar position; therefore, the first rain observed must have fallen from the seeded portion of the cloud. The ending time of the rain was reported as 1455 E. S. T. By that time, the first seeded cloud as well as the echo from the second cloud (the one to the southwest) had passed on to the east of the station; therefore, it is probable that the total amount of rain observed was a



(a)

(b)

FIGURE 3.—June 30, 1948. 1427:15 E. S. T. Photograph of radar scope (a) and line reproduction (b).

combined result of both the seeded and unseeded clouds. This total amount for the 20-minute period, however, was only a trace; therefore, if the seeding of the cloud did cause precipitation, it must have been very light and insignificant economically, since a combination of both artificially produced and naturally produced rain resulted in only a trace of rain reaching the ground. It may be observed that none of the echoes passed directly over the airbase, but the echoes were very small and it is probable that a measureable amount of precipitation would not have been recorded even if the center of the echoes had passed directly over the observation point.

In summary, the sequence of events that occurred following the first seeding run, as correlated from visual observations and radar scope pictures,[2] was as follows:

1. Approximately 12 minutes after the first seeding, a small cloud echo appeared on the radar scope at 210°, 18 miles from Jamestown, Ohio (figs. 3 (a) and 3 (b)). The calculated position of the first seeded area, however, indicated that its position was about 2 miles east-northeast of the echo (fig. 3 (b)).

Since there may have been some error in calculating the movement of the seeded area, a check of the relative positions of the first and second seeded areas was made at the time of the second seeding. Visual observations made at the beginning of the mission indicated that the tower seeded on the second run should be to the southwest of the one seeded on the first run. Since that relationship existed between the two seeded areas at 1427:15 E. S. T. (fig. 3 (b)) and at the time of the second seeding (fig. 7 (b)), it was assumed that the extrapolated movement of the first seeded area must be approximately correct; therefore, the echo that formed on the radar scope at 1427:15 E. S. T. must have been in the second tower and not from the tower that was seeded.

2. A position at which a second echo formed northeast of the first one at 1428:05 E. S. T. agreed closely with the calculated position of the first seeded area at that time (figs. 4 (a) and 4 (b)). Consequently, it was concluded that although the seeded cloud produced a radar echo about 12

[2] In figs. 3 through 8, line diagrams of the photographic radar scope pictures are included, since some details of the photographs may be lost in reproduction.

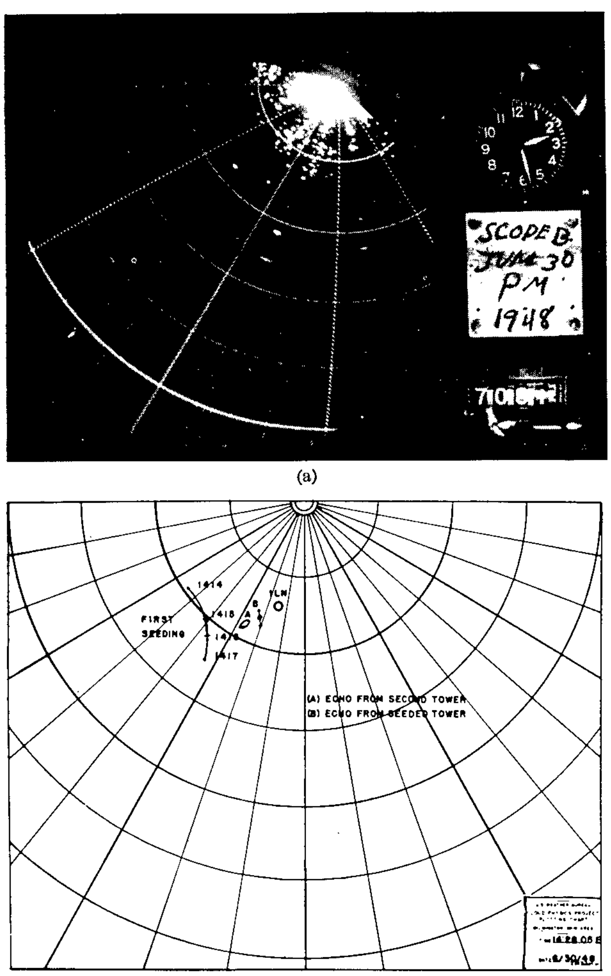


FIGURE 4.—June 30, 1948. 1428:05 E. S. T. Photograph of radar scope (a) and line reproduction (b).

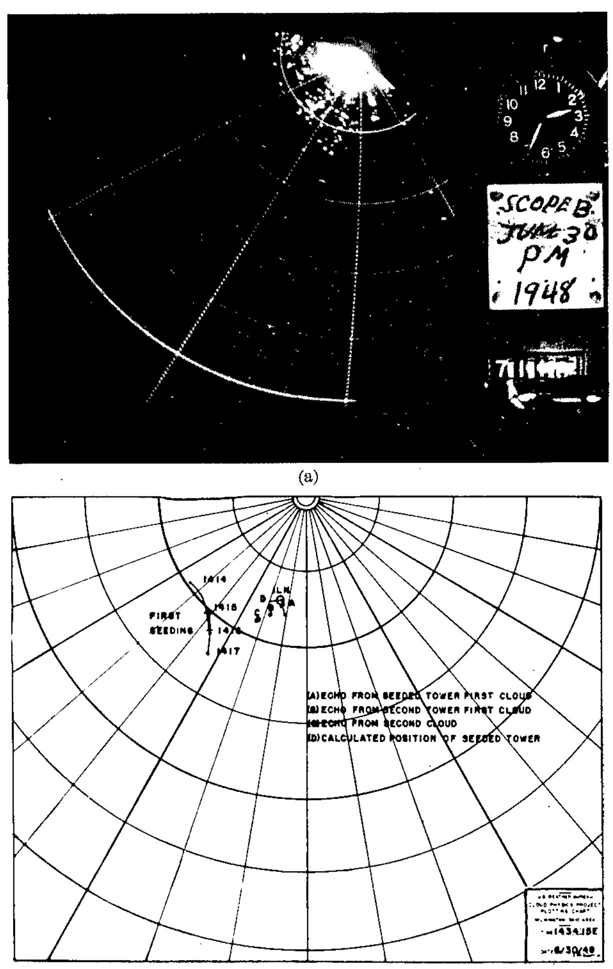
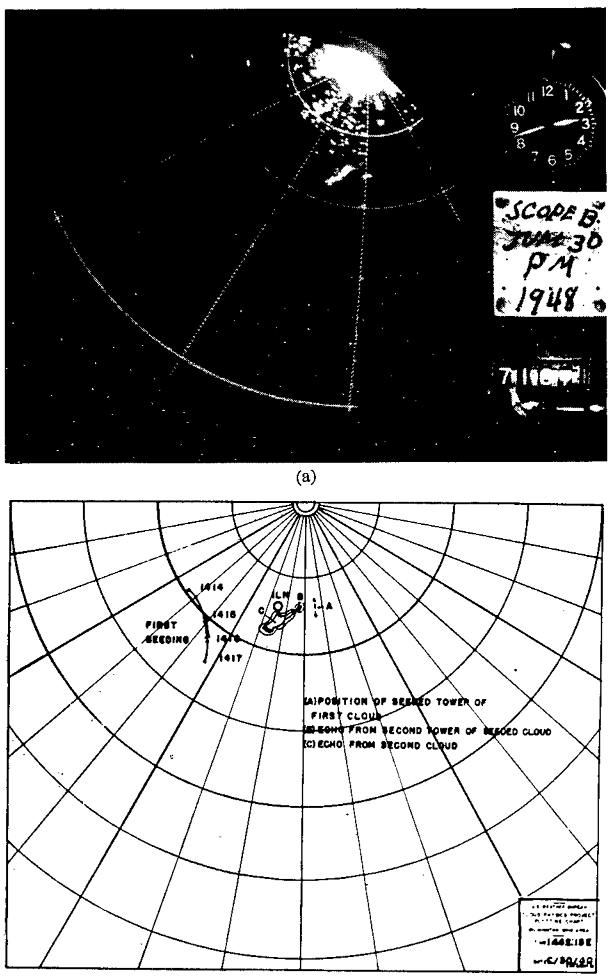


FIGURE 5.—June 30, 1948. 1434:15 E. S. T. Photograph of radar scope (a) and line reproduction (b).

minutes after seeding, rain fell from an unseeded portion of the cloud previous to its fall from the seeded portion. The two echoes eventually joined together, and by 1434:15 E. S. T. the northeast end of the echo had almost disappeared from the scope (figs. 5 (a) and 5 (b)).

3. At the time the northeast end of the echo was disappearing from the scope, another echo began to form southwest of the seeded cloud (figs. 5 (a) and 5 (b)). The echo gradually spread to the northeast and merged with the echo that remained in the southwest portion of the seeded cloud. The position of the small portion on the northeast end of the large echo at 1442:15 E. S. T.



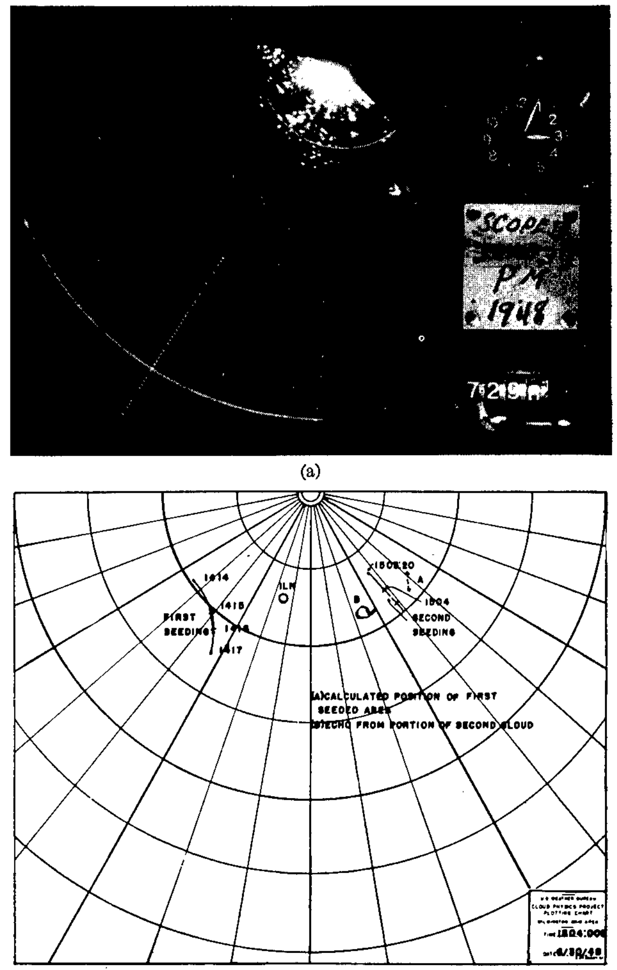
(a)

(b)

FIGURE 6.—June 30, 1948. 1442:15 E. S. T. Photograph of radar scope (a) and line reproduction (b).

(figs. 6 (a) and 6 (b)) agreed very well with the calculated movement of the echo from the second tower of the seeded cloud.

4. By the time of the second seeding, the echo from the seeded cloud had disappeared entirely from the radar scope. The remaining part of the echo must have been from a portion of the second cloud. The position (figs. 7 (a) and 7 (b)) at 1504 E. S. T. was in close agreement with the calculated movement of the second cloud. (Note:



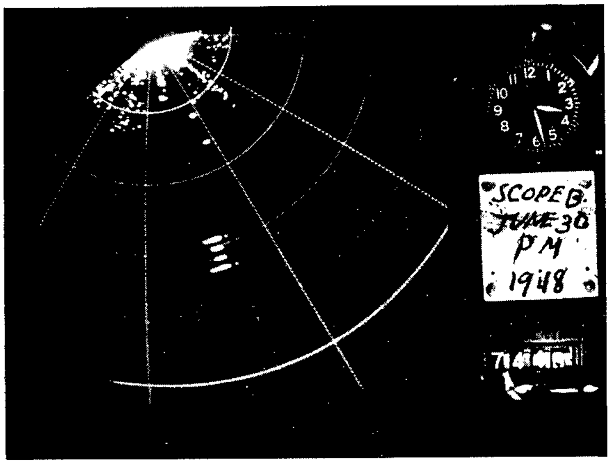
(a)

(b)

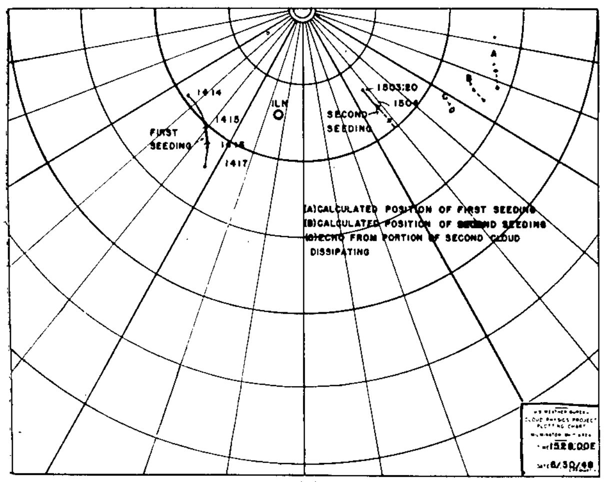
FIGURE 7.—June 30, 1948. 1504 E. S. T. Photograph of radar scope (a) and line reproduction (b).

It must be kept in mind that only that portion of a cloud from which precipitation is falling is indicated on the radar scope.) The echo from the second cloud remained on the radar scope until 1528 E. S. T. (figs. 8 (a) and 8 (b)). No echo was observed to form as a result of the second seeding.

Based on the results of Byers and Braham's [3] study of thunderstorm structure and development, a possible interpretation of the results of this June 30 mission may be made. Byers and Braham have found that a thunderstorm is usually made up of several independent circulation cells. Each cell goes through a similar life history, and its development does not depend upon a redistribution of energy within the cloud; one cell does not develop at the expense of another one. The authors do recognize the fact, however, that the cold downdraft from one cell of a thunderstorm may act as a micro cold front and thereby be the determining factor in initiating the development of neighboring cells; but once the new cell has started, they conclude, its continued propagation is not due to the transfer of energy from neighboring cells. That a neighboring cell may dissipate



(a)



(b)

FIGURE 8.—June 30, 1948. 1528 E. S. T. Photograph of radar scope (a) and line reproduction (b).

while a new one is developing is probably due to the fact that the old cell, once the rain has started, is very close to the dissipating stage anyway; therefore, its dissipation is a normal step in its life cycle and not the result of funneling energy from it to the new one. If the above processes do take place in thunderstorms, and presumably cumulus congestus clouds, they would remove any possibility that the seeding in one portion of a cloud might cause the development of another section unless that seeding resulted in the formation of an appreciable amount of rain or the formation of a sustaining downdraft in the cloud. Since on June 30, a relatively small amount of dissipation was observed, it is doubtful that the seeding could have created a downdraft sufficient to form a pseudo-cold front and start the development of another section of the cloud. This would especially be true as the first rain area started upwind from the seeded position. Formation of rain in the unseeded portion of the cloud and its spreading to the seeded area may indicate that the seeding had little or no effect on the eventual production of rain observed in the seeded area. The rain in the seeded area may actually have been triggered by the formation of a micro cold front in the downdraft of the unseeded portion of the cloud as the cold current moved along the earth's surface. The knowledge gained by the use of radar that rain fell from the unseeded part of the cloud before it fell from the seeded portion provided a logical interpretation of the data that could not otherwise have been obtained.

Although there would have been no serious error made in arriving at the conclusions of this particular mission without radar control, the example indicates that exaggerated conclusions could be obtained under similar circumstances when measurable amounts of rainfall are recorded. Even in this case, however, a slightly different conclusion was obtained than visual observations alone would have indicated.

Seeding of May 17, 1948.—As an example of the further use of radar in the analysis of cloud seeding missions, data from this mission are included in figures 9 through 15. A supercooled cumulus cloud was seeded on three successive runs, and figures 10, 11, and 13 are radar scope pictures coinciding with the times of the respective runs. Light icing was picked up and light to

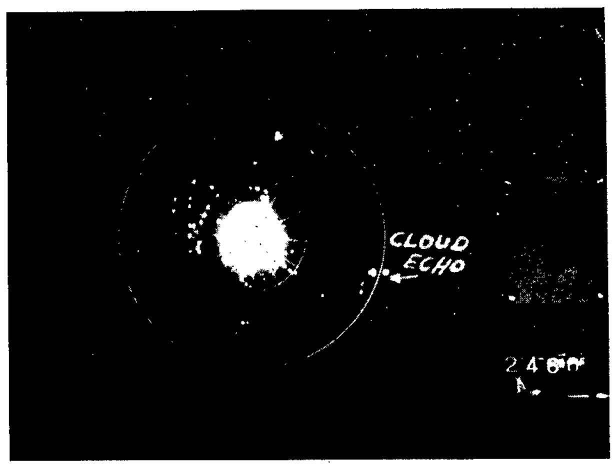


FIGURE 9.—May 17, 1948. 1349 E. S. T. Photograph of radar scope A showing cloud echoes present northeast of operations area at time of first seeding.

FIGURE 10.—May 17, 1948. 1349 E. S. T. Photograph of radar scope C at time of first seeding.

FIGURE 11.—May 17, 1948. 1402:20 E. S. T. Photograph of radar scope at time of second seeding.

moderate turbulence was encountered on each run, but the amount of moisture observed was very small. Nevertheless, a cloud echo did appear

FIGURE 12.—May 17, 1948. 1410 E. S. T. Photograph of radar scope 8 minutes after second seeding.

on the radar scope about 8 minutes after the second seeding (fig. 12). It did not grow to an appreciable size, and observers in the low observa-

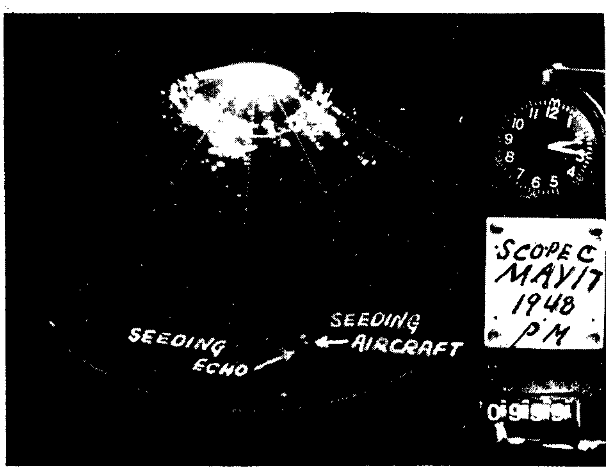


FIGURE 13.—May 17, 1948. 1414:40 E. S. T. Photograph of radar scope at the time of third seeding.

FIGURE 14.—May 17, 1948. 1416 E. S. T. Photograph of radar scope after third seeding.

tion plane reported that the rain was light and did not reach the ground. The echo finally disappeared from the scope about 27 minutes after the initial run (fig. 14), but observers reported that light rain fell from the cloud for an additional 20 minutes. In figure 13, the echo from the seeded cloud is indicated at 167°, 40 miles from Jamestown, Ohio. A portion of the echo is obscured by the radar return from the seeding aircraft. In figure 14, the large radar return from the low observation plane at 1416 E. S. T. is indicated just north of the echo from the seeded cloud. Figure 15 is a composite of figures 10 through 14. The direction and speed of movement of the seeded areas were obtained in a manner similar to that discussed in the June 30 summary. Since three definite positions of the cloud were known and the movement of the resulting echo could be determined, the speed and direction could be checked with reasonable accuracy. Values computed thus agreed within the limits of error in measurement with the radio-winds recorded simultaneously with the first seeding run and within 4

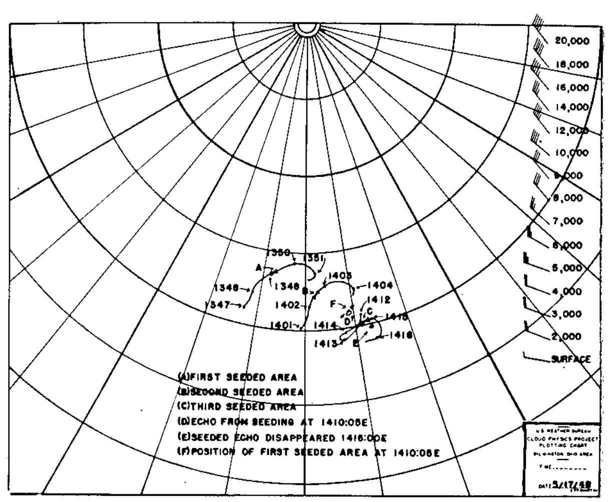


FIGURE 15.—May 17, 1948. Line diagram showing composite results of radar observations of three seeding runs.

miles of the seeded area. It may be noted that the only cloud echoes at the time of the first seeding were a considerable distance from the area of operations (fig. 9). For a more complete discussion of this mission, see the chronological listing in the next section of this report.

Seeding of July 30, 1948.—Still another example of the use of radar control in cloud seeding operations may be cited from the data of the third seeding of July 30. The seeded cloud had two towers; observers in the seeding aircraft reported that the southern tower was the most pronounced. The seeding was performed in the northern tower of the cloud and the drop was made from above the cloud top. From pictures of the radar scope, it was determined that the southern portion of the cloud was appearing as an echo at the time of the seeding run (figs. 16 and 17). The temperature of the environment of the top of the seeded portion of the cloud was near 0.0° C. Since the southern tower was considerably higher, it is possible that at least a portion of the cloud was supercooled. The north-south diameter of the cloud, as indicated by the position of the seeding aircraft at the time of the seeding run and the echo position from part of the cloud (fig. 18), was at least 4 miles. The northeast-southwest diameter was several miles greater than the north-south one.

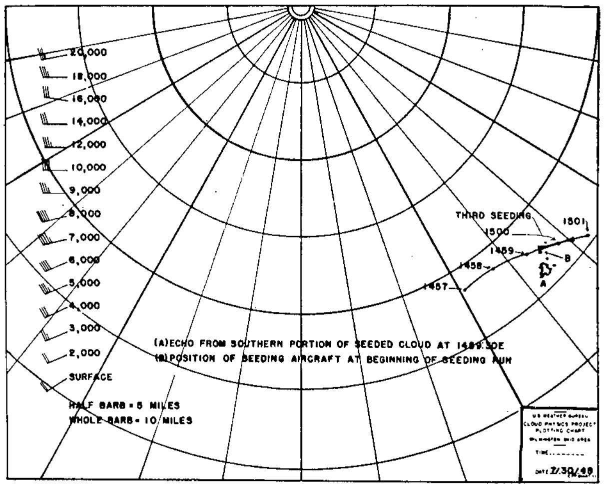


FIGURE 18.—July 30, 1948. Line diagram showing results of radar observations at the time of the third seeding.

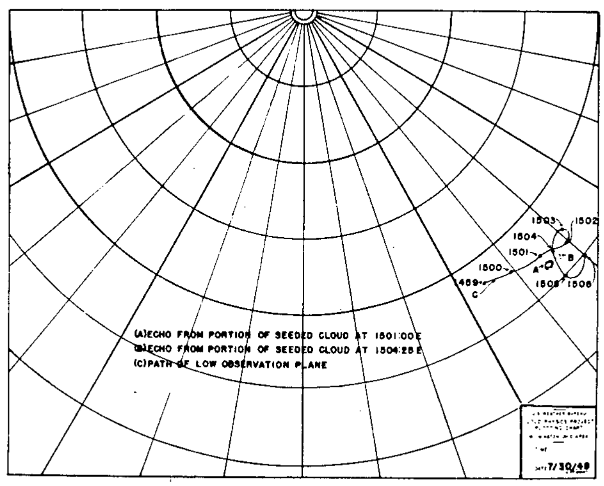


FIGURE 19.—July 30, 1948. Line diagram showing results of radar observations following the third seeding.

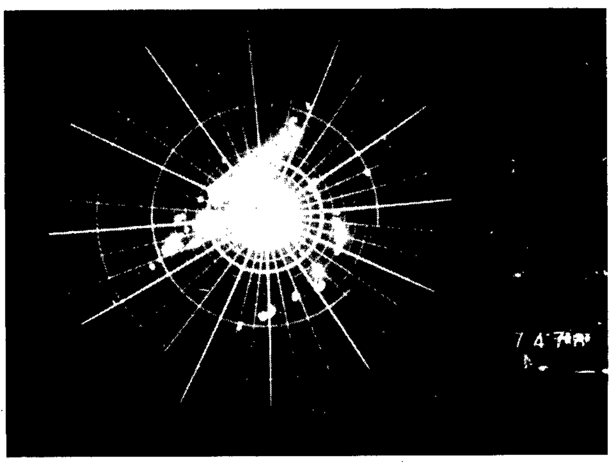


FIGURE 16.—July 30, 1948. 1449 E. S. T. Photograph of radar scope prior to the third seeding.

FIGURE 17.—July 30, 1948. 1459 E. S. T. Photograph of radar scope at the time of the third seeding.

The low observation plane made a run under the seeded portion of the cloud between 1501 E. S. T., and 1502 E. S. T., and the observers reported that there was no precipitation falling from the cloud (fig. 19). Between 1504 E. S. T. and 1505 E. S. T., however, another run was made, and observers reported light rain at that time, but (fig. 19) the aircraft passed not only under the seeded area but also under the portion of the cloud that was appearing as an echo on the radar scope.

For further details concerning this mission, see the chronological listing in the next section of this report.

EXAMPLE OF CLOUD MODIFICATION BY MECHANICAL MEANS

Recent work done by Stommel [1], Austin [2], Byers and Braham [3] seems to indicate that the cumulus cloud has a lapse rate very close to that of its environment. Austin arrived at theoretical lapse rate values by assuming a definite amount of entrainment of the environmental air into the cloud. Stommel has derived mathematical expressions for computing the rate of entrainment into the cloud when the temperatures of the cloud air and its environment are known. Byers and Braham, using a method similar to that of Austin's, were successful in verifying the theory by empirical means. By assuming a definite amount of entrainment and then computing the up- and downdrafts in thunderstorms, they compared the resulting surface temperatures in the cold downdrafts with the temperatures actually observed. The values they obtained agreed very closly with the observed temperatures. It appeared from these investigations that a strong downward impulse, or downdraft, imparted to a cloud by mechanical means might modify the cloud in an important manner.

August 25, 1948.—In an effort to evaluate the importance of mechanical effects alone, an experiment was carried out on August 25, 1948, in which a P–61 aircraft was flown through the tops of cumulus clouds at almost stalling speed. The plane was flown through the clouds at an angle of approximately 45° with the horizontal, and spent an estimated 3 seconds in the cloud, thus communicating to it considerable downward momentum. The P–61 was the only aircraft flown on the mission, but the clouds were picked so that ground observations of the results could be made from Clinton County Air Force Base. The clouds were small, flat cumuli in which some natural dissipation was observed throughout flight. After the aircraft was flown through the clouds, there was a marked acceleration in the rate of dissipation of the cloud treated by the aircraft as compared with the natural dissipation of neighboring clouds. Pictures of a sequence of events following one of the runs are included in figure 20, representing various stages of the dissipation observed over a period of about 10 minutes.

Attention is drawn to the fact that the dispersal of CO_2 snow or water into a cloud both cools the cloud and communicates downward momentum to it. It may well be that these are important mechanisms in producing cloud modification and dispersal.

FIGURE 20.—Sequence of cloud pictures from cloud treatment by mechanical means on August 25, 1948, showing stages in cloud dissipation. (a) View of cloud immediately after P–61 aircraft was flown through it. (b) View of cloud 5 minutes after aircraft was flown through it. (c) View of cloud 10 minutes after aircraft was flown through it.

DESCRIPTIONS OF INDIVIDUAL SEEDING OPERATIONS

Summaries of each of the operations conducted for seeding cumuliform clouds during the spring and summer of 1948 conclude this report. Results given in each case are based upon an analysis procedure such as that described in the preceding examples.

In order to show the temperature-moisture conditions which existed aloft at the time of seeding, pseudo-adiabatic charts for each day of operation are included following the summaries.

CLOUD SEEDING OF MARCH 16, 1948

Synoptic situation.—At 1330 E. S. T., the area of seeding operations was immediately ahead of a cold front. The front was evidently in the seeded area at the time of seeding, and it probably played an important part in the development of the cumulus clouds that were seeded. A few widely scattered showers had fallen to the east of the front prior to 1330 E. S. T.

Conditions of seeding.—Beneath a cirrus and cirrostratus broken cloud deck were a great many swelling cumuli with bases at 4,500 feet mean sea level. Two cumulus clouds with tops at 15,500 feet and 17,250 feet, respectively, were seeded. Temperatures were +7.0° C. at 4,500 feet; −15.0° C. at 15,500 feet; and −19.0° C. at 17,250 feet. The first cumulus was growing in circumference but not gaining in height when seeded. This was typical of other swelling cumuli within sight of observers in the seeding plane when the first cumulus was seeded.

The second cumulus, seeded 38 minutes later, was still growing, but very slowly, at the time of seeding. Several cumuli, estimated to be 10 miles from the seeded one, had veils around them, with the tops extending through the veils. Within 38 minutes after the second seeding, several cumuli, estimated to be 4 miles or more distant from the seeded one, had developed anvil tops and were producing heavy showers.

Rate of seeding.—Twenty pounds of dry ice were deposited in the tops of each of the two cumulus clouds. The first drop was made in 18 seconds and the second in 15 seconds.

Time and duration of seeding:

1st seeding: 1414 E. S. T.; 18 seconds.
2d seeding: 1452 E. S. T.; 15 seconds.

(Note: Actual times not known; those indicated are only approximate.)

Results.—Seeding had no apparent effect on the first cumulus cloud. It continued to expand horizontally at about the same rate as before the seeding, and the height of the top and the texture did not change. Within 10 minutes after the second seeding, a crease developed in the cloud along the seeded line. Within 28 minutes after the seeding, the crease had so developed that the cloud split and observers could see the ground between the two portions. The seeded cloud did not continue to grow in diameter or in height after the seeding, although neighboring cumulus clouds did continue to grow.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual).
   b. 2d seeding: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Aerial observations (visual).
   b. 2d seeding: Aerial observations (visual).

Comments.—The clouds seeded were potential thunderstorms. For evidence: Several similar clouds in a radius of 10 miles of the seeded clouds did develop thunderheads within 1 hour and 30 minutes after the first seeding and within 40 minutes after the second seeding. The seeded clouds looked quite similar to these others before seeding. They were over 10,000 feet thick, and temperatures in the tops of the clouds were well below freezing. Observers were not certain that ice crystals were not already present before seeding, but they did not think that was the case. All things seemed favorable, but no precipitation was caused by the seeding. One can only conclude that either the seeding actually discouraged the development of the cumulus clouds or that nature had already decreed that the ones picked for seeding were not the ones chosen for development that day and that the seeding was not potent enough to change nature's plans. The radar was partially inoperative so that it was not possible to vector other planes into position for observing the clouds. However, observers in the seeding ship were confident in their observations that the seeding did not cause the clouds to grow or to precipitate.

CLOUD SEEDING OF MARCH 31, 1948

Synoptic situation.—At 1330 E. S. T., a deep, low-pressure system was centered over southern Lake Michigan. The area of seeding operations was in the warm section of the low-pressure system. Considerable cloudiness and showers were occurring over southwestern Ohio. Wilmington, Ohio, was in a strong south-to-north flow of air.

Conditions of seeding.—Swelling cumulus clouds with bases at 5,500 feet mean sea level and tops at about 18,500 feet were seeded twice. The clouds were building at the time of seeding, and their sharp edges together with the observed temperatures in the clouds indicated that they were composed of supercooled water droplets. The third seeding was through a slightly depressed portion of the cloud deck between towering cumuli. The base of the flat portion was at 5,500 feet mean sea level, and the top extended upward to 17,000 feet. On the first two seedings, the temperature varied from +7.0° C. at the base to −23.0° C. at the top; and on the third run, the temperatures ranged from +7.0° to −20.0° C.

Rate of seeding.—Dry ice pellets were dropped at the rate of approximately 27 pounds per mile on all seeding runs.

Time and duration of seeding:

1st seeding: 1115:36 E. S. T.; 25 seconds.
2d seeding: 1151:35 E. S. T.; 25 seconds.
3d seeding: 1242:48 E. S. T.; 25 seconds.

Results.—It is probable that light rain may have fallen from the seeded clouds after the first lot of dry ice was dropped. Since the second seeded cloud was never located by the low observation plane, it is not known whether precipitation fell from the base or not. In any event, there was no precipitation echo on the radar scope in the seeded area; therefore, if precipitation did fall, it must have been very light. Rain did not occur in the seeded area after the third seeding run. All three seedings, however, did produce changes in texture and color of the clouds, and the third seeding caused dissipation which resulted in a hole in the cloud through which the ground could be seen.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual).
2. Precipitation:
   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—The negative precipitation results were significant, since it was raining in close proximity to all the seeded areas. Approximately 7 minutes after the first seeding run, a radar echo of precipitation was observed at 1123 E. S. T. in the seeded area, but rain had been reported by the low observation plane at 1120 E. S. T. about 10 miles northwest of the seeded area, and another strong precipitation echo was observed 18 miles southeast of the seeded area; therefore, the significance of the results was questionable. The second and third seeding runs failed to produce precipitation echoes on the radar scope, although pronounced echoes were noted in the vicinity of the seeded areas. On the third seeding run, the low observation plane reported light rain, but verification of its position from the track on the radar scope indicated that the rain was coming from precipitation areas 8 miles northwest of the seeded area.

The positive structural changes in the clouds were significant, at least on the first seeding run, since conditions were considered to be theoretically ideal for nucleation. Furthermore, other clouds in the area were building up at the same time that the seeded clouds were changing texture and partially dissipating.

CLOUD SEEDING OF APRIL 27, 1948

Synoptic situation.—A cold front was oriented northeast-southwest over the west-central part of Ohio and southern Indiana at 1330 E. S. T. The seeding runs were made in the warm sector of the low pressure system about 50 miles ahead of the cold front. The front produced heavy showers and hail as it passed over the radar station at Jamestown, Ohio.

Conditions of seeding.—Cumulus clouds were seeded four times. The bases were at about 5,500 feet mean sea level and the tops near 15,000 feet on the first run and 13,000 feet on the last three runs. The temperature at the bases of the clouds was +11.0° C. and varied from −3.0° to −8.0° C. at the tops.

Rate of seeding.—Varying amounts of ⅜-inch dry ice were dumped into the cumulus clouds. The first two drops were made at the rate of 2.2 pounds per mile and 3.4 pounds per mile, respectively. The last two were instantaneous drops of 40 pounds and 60 pounds of granulated dry ice. An effort to dye the seeded clouds by dropping a powdered dye with each seeding run was ineffective.

Time and duration of seeding:

1st seeding: 1421:30 E. S. T.; 25 seconds.
2d seeding: 1433:35 E. S. T.; 31 seconds.
3d seeding: 1446:38 E. S. T.; photo-hatch drop—time unknown.
4th seeding: 1449:51 E. S. T.; 7 seconds.

Results.—Precipitation and dissipation results were negative on all except the second run. Very light rain occurred approximately 29 minutes after the second seeding.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual)
2. Precipitation:
   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Sky condition was very chaotic and the results observed were not definite, but it was generally agreed that the dissipation results were negative.

A few drops of rain were reported by observers in the low aircraft about 9 minutes after the second seeding, but the indications were that the plane was about 8 to 9 miles west-southwest of the seeded cloud at the time the rain was reported. Although a precipitation echo was observed on the radar scope after the second seeding, it was very weak and diffuse in comparison with natural echoes occurring at the same time. Since natural showers were observed on the radar scope at the time of all four seedings, the negative results observed on three of the drops were far more significant than the positive result. A logical conclusion is that the positive result was obtained from a cloud that would have produced a natural shower anyway. The seeding operation may have hastened its development. The economic importance of the positive result was nil in view of the radar indications that the precipitation produced was very light and insignificant as compared with natural showers nearby.

CLOUD SEEDING OF MAY 11, 1948

Synoptic situation.—The 1330 E. S. T. surface map indicated a low pressure trough running from northeastern Ohio to southwestern Indiana, with a stationary front across northern Ohio and central Indiana. A squall line indicated on the map ran north-south through central Indiana, but it was apparently closer to the Clinton County Air Force Base than was indicated. A thundershower passed over the base about 1340 E. S. T., and throughout the seeding mission the line of shower activity indicated on the radar scope was south-southeast of the airfield. Such a movement of shower activity would indicate the squall line to be south and east of the seeding area. The seeding time was from 1510 E. S. T. to 1525 E. S. T. Rain showers passed over the entire micro station network from northwest to southeast between 1345 E. S. T. and 1420 E. S. T.

Conditions of seeding.—Cumulus clouds were seeded three times. Bases of them were at about 5,000 feet mean sea level, and the temperatures were +15.0° C. The tops varied from 14,000 feet mean sea level with temperatures of −3.0° C. on the first run, to 12,500 feet with temperatures of 0.0° C. on the second and third runs, respectively. Visual observations of the sun's disk through the cloud elements indicated that the clouds were composed of water droplets; the third seeding drop was made inside the cloud. The freezing level was near 12,500 feet mean sea level.

Rate of seeding.—On the first run, 10 pounds of dry ice were dropped at the rate of 6 pounds per mile; on the second run, a lump drop of 30 pounds was made; on the third run, 30 pounds were dropped at the rate of 26 pounds per mile.

Time and duration of seeding:
- 1st seeding: 1510:50 E. S. T.; 30 seconds.
- 2d seeding: 1517:40 E. S. T.; 8 seconds.
- 3d seeding: 1524:55 E. S. T.; 20 seconds.

Results.—Observations of dissipation were made after the first two seedings, but all clouds were observed to be dissipating. After the third run, the top of the cloud grew about 2,500 feet upward, but the growth was not believed to have been caused by seeding.

Method of verification:
1. Structural:
   a. 1st seeding: Aerial observations (visual and photographic).
   b. 2d seeding: Aerial observations (visual).
   c. 3d seeding: Aerial observations (visual).
2. Precipitation:
   All seedings: Radar pictures showing no precipitation in seeded area.

Comments.—Since other clouds in the area were dissipating, the dissipation results were not conclusive. After the first seeding, observers reported that the seeded cloud broke up while neighboring clouds did not; there is a probability that the seeding did hasten the natural process of dissipation. Results of the other two seedings may or may not have been significant.

A low observation plane did not fly the mission; consequently, visual observations of precipitation below the seeded clouds were not made. The radar scope did not indicate any precipitation in the seeded areas; therefore, if any rain did occur it must have been very light. The seeded area did not pass over a rain gage.

CLOUD SEEDING OF MAY 17, 1948

Synoptic situation.—The seeding area was located at 1330 E. S. T. on the eastern side of an anticyclone in a north-to-south circulation. Clouds were broken cumuli and stratocumuli, with light shower activity along the West Virginia-Ohio boundary. Columbus, Ohio, reported 0.04 inch of rainfall between 0630 E. S. T. and 1330 E. S. T.

Conditions of seeding.—Cumulus clouds were seeded five times. Three successive drops were made in the first cloud (fig. 21) and two drops in the second cloud. The last drop in the first cloud was made after a precipitation echo was picked up from it on the radar scope. The last drop in the second cloud was made as the plane flew around in the edges of it. Bases of the clouds were at about 4,400 feet mean sea level on the first three runs and at about 4,800 feet on the last two runs. The tops of the clouds ranged from 11,500 feet mean sea level on the first three runs to 12,500 feet on the last two. Temperatures ranged from +8.0° C. at the base of the first cloud to −5.0° C. at the top, and from +8.0° C. at the base of the second to −7.0° C. at the top. The freezing level was near 7,750 feet mean sea level.

Rate of seeding.—Twenty pounds of dry ice were released in an instantaneous drop on the first seeding. On the second and fifth seedings, drops were made at the rates of 7 pounds and 6 pounds per mile, respectively. On the third and fourth runs, dry ice was dropped from the electric dispensing unit at the rates of 10 pounds and 7 pounds per mile, respectively, and 20 pounds were released through the photo-hatch at the same time. Dry ice pellets of ½- and ¾-inch in diameter were used on all seedings.

Time and duration of seeding:
- 1st seeding: 1349 E. S. T.; 5 seconds.
- 2d seeding: 1402:20 E. S. T.; 25 seconds.
- 3d seeding: 1414:40 E. S. T.; duration unknown.
- 4th seeding: 1447:20 E. S. T.; 10 seconds.
- 5th seeding: 1459:35 E. S. T.; 25 seconds.

Results.—After the first seeding, a slight change in texture of the cloud was observed. After the next run, a trough formed and deepened steadily; after the third run, a hole approximately 150 feet in diameter formed. (See fig. 21 (c).)

The second cloud changed texture and formed a trough soon after the initial drop into it. After the next drop, some dissipation was noted and

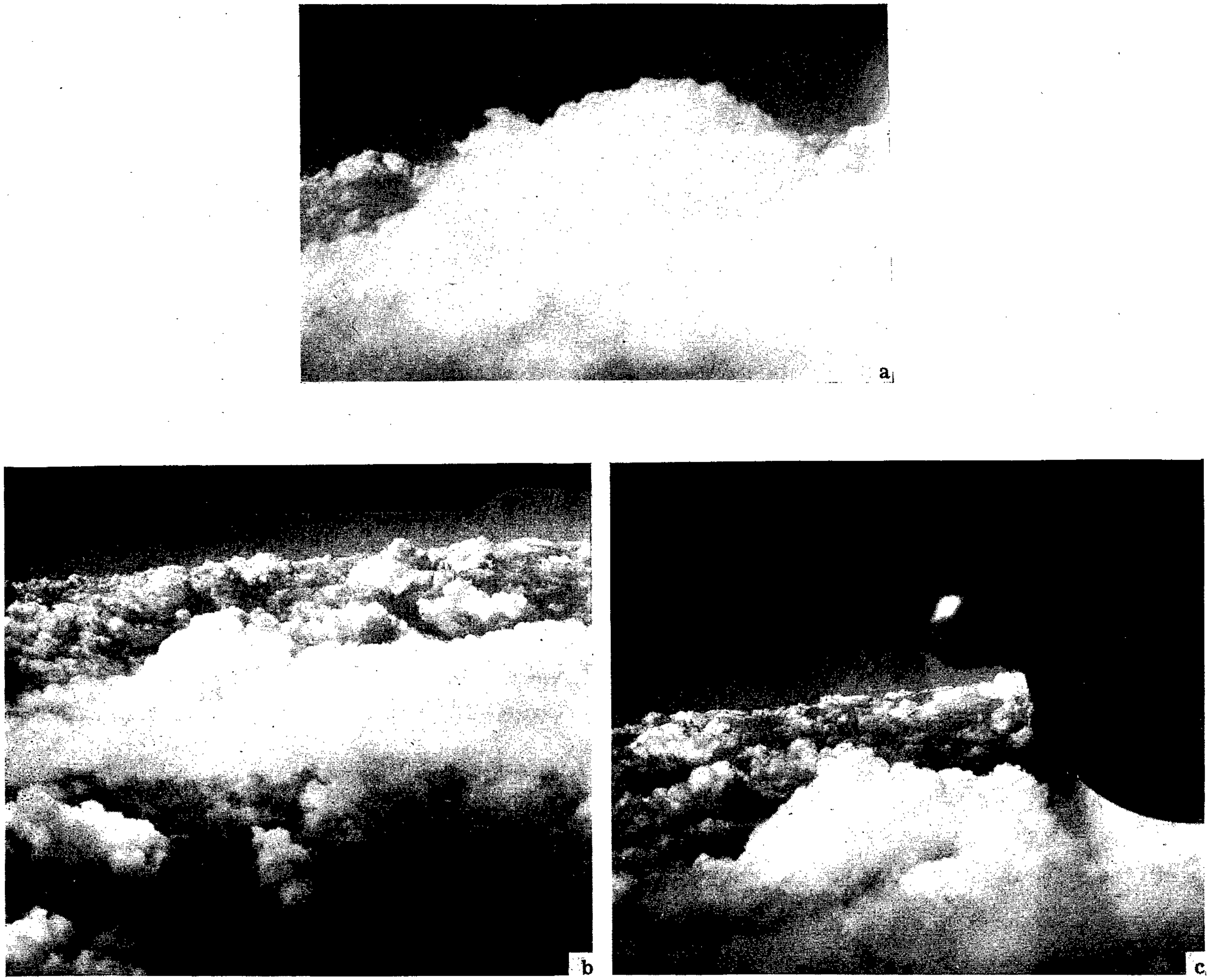


FIGURE 21.—Sequence of cloud pictures from the first cloud seeded on May 17, 1948. (a) 1340 E. S. T. View of cloud to be seeded. (b) 1422 E. S. T. View of cloud showing trough which appeared approximately 8 minutes after the third drop of dry ice. (c) 1423 E. S. T. View of cloud showing trough as it appeared approximately 9 minutes after the third drop of dry ice.

then one side began to build slightly. The estimated amount of building was about 1,000 feet.

Precipitation fell and a cloud echo appeared on the radar scope from the first seeded cloud approximately 8 minutes after the second seeding (fig. 12), but the rain was not believed to have reached the ground. The echo disappeared from the radar scope about 27 minutes after the initial seeding, but visual observations made from the low-flying aircraft reported that light rain continued for another 20 minutes.

Light rain fell and a cloud echo appeared on the radar scope from the second cloud about 10 minutes after the initial seeding, but the rain did not reach the ground. The seeded cloud passed over a Weather Bureau rain gage located at Peebles, Ohio, about 1528 E. S. T., but no precipitation was recorded. The echo disappeared from the scope about 45 minutes after the first run on the cloud.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual and photographic).
   (3d seeding: See figs. 21 (b) and (c).)
2. Precipitation:
   a. 1st seeding: Aerial observations (visual).
   b. 2d seeding: Aerial observations (visual) and photographs of radar scope (figs. 11 and 12).
   c. 3d seeding: Aerial observations (visual) and photographs of radar scope (figs. 13 and 14).
   d. 4th seeding: Aerial observations (visual) and photographs of radar scope.
   e. 5th seeding: Aerial observations (visual) and photographs of radar scope, and rain gage data from Peebles, Ohio.

Comments.—Dissipation and precipitation results were significant. Clouds in the vicinity of the seeded area were observed to be neither dissipating nor building, but reports of turbulence in the clouds before seeding indicated that a slight degree of building was in progress. The only precipitation echoes, other than from the seeded clouds, were located a considerable distance northeast of the operations area (fig. 9). After seeding the second cloud for the last time, a plane made a run through the cloud from 9,000 feet to 6,000 feet mean sea level. Light snow and rain mixed were observed as the plane entered the cloud, but only light rain was observed at 6,000 feet.

CLOUD SEEDING OF MAY 18, 1948

Synoptic situation.—The seeded area at 1330 E. S. T. was on the southeastern side of an anticyclone in a north-to-south circulation. Variable amounts of cumulus clouds were present over Ohio and Indiana. Wilmington, Ohio, recorded a trace of precipitation for the 6-hour period prior to 1330 E. S. T., and a few thundershowers were occurring along the extreme southern border of Ohio at map time.

Conditions of seeding.—Cumulus clouds were seeded three times. The bases of the clouds were at 5,200 feet mean sea level, and the tops ranged from 15,150 feet on the first seeding to 15,000 feet on the second and third runs. Temperatures at the bases were +8.0° C. and at the tops, −9.0° C. Showers were occurring in the vicinity of the seeded areas on all three seedings. A cloud giving an echo on the radar scope was seeded on each of the last two runs. The freezing level was at approximately 8,250 feet mean sea level.

Rate of seeding.—Dry ice pellets of ½ to ¾ inch in diameter were dropped at the rate of 15, 6, and 7 pounds per mile, respectively, on the three seeding runs. Lump drops of 20 and 30 pounds, respectively, were made also on the second and third runs.

Time and duration of seeding:

1st seeding: 1351:02 E. S. T.; 23 seconds.
2d seeding: 1420:40 E. S. T.; 57 seconds.
3d seeding: 1451:15 E. S. T.; 1 minute and 10 seconds.

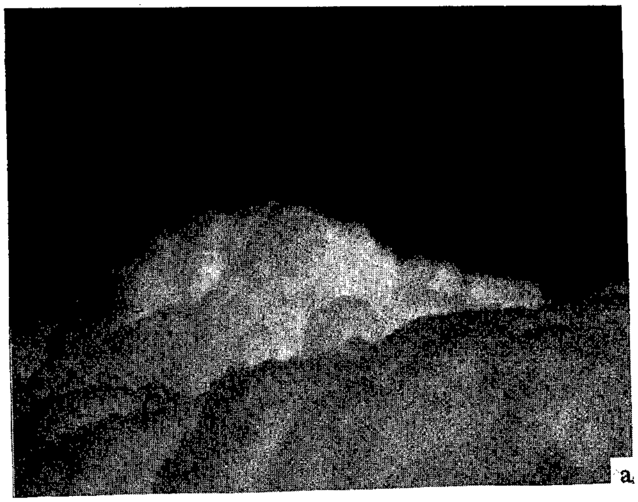
Results.—A slight change in texture and a small amount of dissipation were observed after the first seeding. A change in texture and a hole through the cloud resulted from the second seeding. A change in texture plus a faint cleavage line along the seeded path were the only results observed after the third seeding (fig. 22).

The areas seeded on the second and third runs were already appearing as echoes on the radar scope. Since precipitation was falling from the clouds before seeding, the precipitation results observed lacked significance. Although the low observation plane reported light to moderate precipitation, enough evidence was available to indicate that the rain was not falling from the seeded clouds. No precipitation was reported to have fallen from the first seeded cloud before or after seeding.

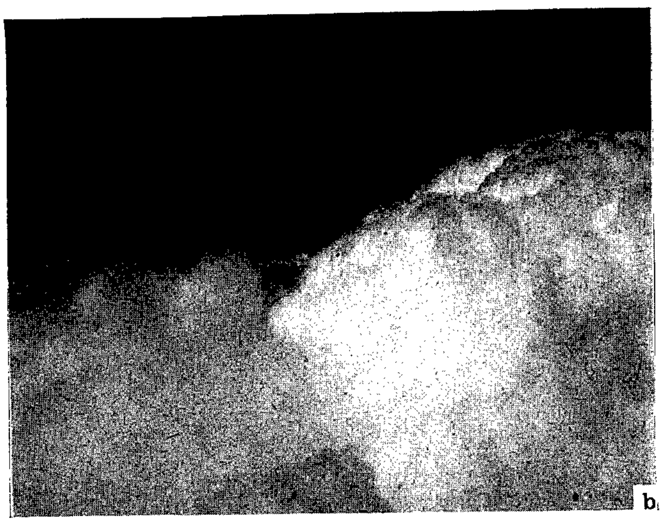
Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual)
   b. 2d seeding: Aerial observations (visual)
   c. 3d seeding: Aerial observations (visual) and photographs of seeded clouds (fig. 22).
2. Precipitation:
   All seedings: pictures of radar scope, coordinating seeded area and plane positions.

Comments.—The lack of precipitation from the first seeded area may have been significant, since other clouds were producing rain nearby. Positive precipitation results after the second and third seedings lacked significance, since rain was falling from the clouds before they were seeded. It is possible that the seeding may have decreased the intensity of the rainfall after the second seeding, but since other precipitation echoes in the immediate vicinity were forming



a



b

c

FIGURE 22.—Sequence of cloud pictures from the third seeding run on May 18, 1948. (a) 1447 E. S. T. View of cloud to be seeded (foreground). (b) 1457 E. S. T. View of cloud approximately 6 minutes after seeding, showing difference in texture between seeded (left) and unseeded (right) cloud. (c) 1500 E. S. T.

on the radar scope, it could not be determined definitely whether or not the dissipation was the result of seeding or of natural processes. As much as 0.09 inch of rain was recorded by the gages of the surface network as a result of natural rain areas close to the seeded area.

The radar echo of the cloud that was seeded on the third run was growing at the time of seeding, and it continued to grow after seeding. The echo finally disappeared by 1528 E. S. T.; but, since an echo of an unseeded cloud just southeast of the seeded cloud disappeared several minutes before the echo of the seeded cloud, the disappearance must have been aided by natural processes and cannot be attributed to seeding alone. Moderate turbulence was encountered and a large amount of ice was picked up in the cloud on the seeding run.

CLOUD SEEDING OF MAY 21, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located south of a cold front oriented in an east-west direction through southern Ohio and Indiana. The seeding operations, which occurred prior to 1330 E. S. T., were performed approximately 50 to 75 miles south of the Jamestown radar site while the cold front was still north of the radar station. Thundershowers were reported at 1330 E. S. T. along the front in southern Indiana and southwest of the front in southwestern Ohio.

Conditions of seeding.—Cumulus clouds were seeded three times. The tops were at 17,000 feet mean sea level on the first run, 18,000 feet on the second, and 18,700 feet on the third. Bases were at 4,900 feet, with temperatures of +16.0° C. Temperatures at the tops ranged from −8.0° C. on the first run, to −10.0° C. on the second, and −11.0° C. on the third. The freezing level was at approximately 12,800 feet mean sea level.

Rate of seeding.—Dry ice pellets of ½ to ¾ inch in diameter were dropped at the rate of 4, 5, and 6 pounds per mile, respectively, on the seeding runs.

Time and duration of seeding:
- 1st seeding: 1112:35 E. S. T.; 45 seconds.
- 2d seeding: 1132:55 E. S. T.; 1 minute and 20 seconds.
- 3d seeding: 1153:10 E. S. T.; 1 minute and 5 seconds.

Results.—After the first seeding, the top of the cloud dropped about 300 feet, with portions of the cloud breaking off to form fractocumuli. Following the second run, there was a slight amount of dissipation, but the cloud built up again to its original height by 1203 E. S. T. The top of the third cloud rose about 3,000 feet after seeding, but it is doubtful whether or not the building was the result of seeding.

No precipitation was observed to have fallen from any of the seeded clouds or from any other clouds within 30 miles of the seeded areas.

Method of verification:
1. Structural:
   a. 1st seeding: Aerial observations (visual) and radar pictures of plane positions.
   b. 2d seeding: Aerial observations (visual) and radar pictures of plane positions.
   c. 3d seeding: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Aerial observations (visual) and radar pictures of plane paths coordinated with the path of the seeded cloud. Also, surface rain gage data from Peebles, Ohio.
   b. 2d seeding: Aerial observations (visual) and radar pictures of plane paths coordinated with the path of the seeded cloud.
   c. 3d seeding: Aerial observations (visual).

Comments.—Positive dissipation results after the first two seedings may have been significant. After the first seeding, another cloud 3 to 4 miles from the seeded one was observed to be building at the time the seeded cloud was dissipating. No icing or turbulence was observed in the first seeded cloud after the dissipation had started. A run made through the second seeded cloud about 3 minutes after the seeding disclosed that there were still some supercooled water droplets present; therefore, the building observed a short time later was not significant. All indications were that there was not enough nucleation to change the cloud completely and permanently.

Since no icing was observed on the initial run into the third cloud, and since snow particles were observed in the cloud top, the cloud was theoretically not suitable for seeding, and the building observed must have been natural and not the result of seeding.

CLOUD SEEDING OF JUNE 15, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located in a weak low-pressure trough, with a high-pressure cell centered to the northwest in Canada. The airbase was situated between two weak frontal systems—a warm front just south of the station and a cold front across northern Ohio oriented in an east-west position. Pressures were falling over the area at 1330 E. S. T. A squall line moved from west to east across the station about 2 hours prior to seeding operations. The seeding was done west of that squall line, but during the mission another line of showers developed just to the west of the area seeded on the second run.

Conditions of seeding.—Cumulus clouds were seeded twice. The bases were at 5,100 feet mean sea level, and the tops varied from 19,000 feet on the first run to 20,000 feet on the second run. The temperatures at the bases were +16.0° C.; near the tops the temperatures were −12.0° and −14.0° C., respectively, on the two runs. The freezing level was at about 12,800 feet mean sea level. Numerous showers were occurring within

a radius of 50 miles of the Clinton County radar site throughout seeding operations.

Rate of seeding.—Dry ice was dropped at the rate of 7 pounds per mile on the first run and 6 pounds per mile on the second. In addition, a lump drop of 25 pounds plus the water spray were used on the second run.

Time and duration of seeding:

1st seeding: 1502:10 E. S. T.; 50 seconds.
2d seeding: 1532:23 E. S. T.; 57 seconds.

Results.—Dissipation and texture changes were observed after both seedings. The top of the cloud seeded on the first drop lowered about 3,000 feet. There was a similar amount of dissipation after the second seeding, but the actual amount of the dissipation was not estimated. According to visual observations, the dissipation was the best to be observed to date in cumulus clouds.

Precipitation results were not definitely determined because a low observation plane did not fly the mission. In any event, no precipitation echoes appeared on the radar scope in the seeded areas; therefore, if any rain did fall, it must have been insignificant.

Method of verification:

1. Structural:
   Both seedings: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Pictures of radar scope at Clinton County Air Force Base.
   b. 2d seeding: Pictures of radar scope at Clinton County Air Force Base and rain gage records from Mount Sterling, Ohio.

Comments.—Dissipation results were observed in the seeded clouds even though they were building at the time of seeding.

Numerous showers were occurring in the immediate vicinity of all seeded areas. The second seeded area passed over the rain gage located at Mount Sterling, Ohio, 16 minutes after seeding, but no rainfall was recorded at that station until 29 minutes after the seeded area had passed on to the east. Since a natural precipitation area was indicated on the radar scope about 5 miles south of the station at the time the rain began, it is more logical to assume that the rainfall recorded was from natural causes and was not induced by the seeding operation.

(Note: It requires about 0.01 inch of liquid water to affect the weighing type rain gage.)

CLOUD SEEDING OF JUNE 18, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was immediately north of a stationary front running east-west across southern Ohio. Columbus, Ohio, was reporting a shower at map time, and drizzle was occurring along the front in the vicinity of the West Virginia-Ohio border. A weak low pressure center was located in the northeastern part of Iowa. The pressure was falling over the entire States of Ohio and Indiana.

Conditions of seeding.—Two cumulus clouds were seeded, each cloud three times. Tops of the seeded portion of the first cloud varied from 20,000 feet mean sea level to 22,000 feet, and the base was at 5,000 feet. In sections of the second cloud that was seeded the tops ranged from 21,000 to 23,000 feet, and the base was at 5,000 feet. Temperatures near the top of the first cloud ranged from $-9.0°$ to $-14.0°$ C., and near the top of the second cloud they ranged from $-11.0°$ to $-18.0°$ C. Temperatures at the bases were $+17.0°$ C. The freezing level was at approximately 14,400 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 4 pounds per mile on the first and sixth seedings. Water was sprayed into the clouds on the second through the fifth seedings.

Time and duration of seeding:

1st seeding: 1432 E. S. T.; 55 seconds.
2d seeding: 1445:49 E. S. T.; 2 minutes and 56 seconds.
3d seeding: 1451:12 E. S. T.; 33 seconds.
4th seeding: 1506:10 E. S. T.; 35 seconds.
5th seeding: 1513:30 E. S. T.; 2 minutes and 5 seconds.
6th seeding: 1526:15 E. S. T.; 2 minutes and 15 seconds.

Results.—Following the first run, the seeded portion of the first cloud stopped its growth, and some of the top dissipated, leaving a small trough formation. After the second run in the same portion of the cloud, the trough continued to grow. The third seeding, in the same section, caused further dissipation of the cloud top. After the fourth seeding, which was the initial run on the second cloud, a small section near the top of the cloud, dissipated. Following the fifth and sixth runs into the second cloud, the cloud changed texture and became fluffy white in appearance. The top stopped growing. Further observations revealed another section of the seeded cloud grew to 28,000 feet mean sea level while the seeded portion remained at about the same height. A varying amount of texture change was observed after each of the seeding runs.

Precipitation results were very doubtful. According to observations of the radar scope at Clinton County Air Force Base, a small echo appeared on the radar scope approximately 34 minutes after the initial seeding of the first cloud; therefore, it is possible that some precipitation may have fallen from a portion of the seeded cloud. According to pictures of the radar scope in the seeding aircraft, an echo from the second cloud was already present at the time of the sixth seeding; therefore, it is possible that some precipitation fell from a portion of that cloud also, but it could not be determined whether or not the echo had been present prior to the initial seeding run.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual) and photographs of the seeded cloud.

(Note: None of the photographs indicated the complete results that were observed visually, but texture changes and some dissipation were apparent.)

2. Precipitation:
   a. 1st seeding: Photographs of radar scope at Clinton County Air Force Base.
   b. 2d seeding: Photographs of radar scope at Clinton County Air Force Base.
   c. 3d seeding: Photographs of radar scope at Clinton County Air Force Base.
   d. 4th seeding: Coordination of available visual observation data.
   e. 5th seeding: Coordination of available visual observation data.
   f. 6th seeding: Coordination of available visual observation data in addition to pictures of the radar scope in the seeding aircraft.

Comments.—The V-Beam radar at Jamestown, Ohio, was inoperative; consequently, the limited range in altitude and distance of the radar at Clinton County Air Force Base made coordination of the mission impossible. All suitable clouds for seeding were outside the range of the radar except for a short period of time at the beginning of the mission. Precipitation results, therefore, were doubtful and were obtained through logical deductions made from data that were available. Natural showers were occurring in the vicinity of all seeded areas except on the first run.

Since the first cloud was building at the time of seeding and the sections that were not affected by the seeding continued to grow while the seeded areas dissipated, it is logical to assume that precipitation from the cloud must have been primarily from natural causes and from portions of the cloud that were not seeded. Furthermore, a cloud echo appeared within 18 to 25 miles of the seeded area several minutes before the echo from the seeded cloud appeared.

Since unseeded portions of the second cloud continued to build after seeding, the precipitation that fell from that cloud must also have been from the areas that were not affected directly by the seeding. Radar pictures in the aircraft were taken beginning at 1524 E. S. T., and the time of the initial run on the second cloud was 1506:10 E. S. T.

Dissipation was observed in the seeded clouds even though they were building at the time of seeding. Other clouds in the immediate vicinity were also building and their tops were changing to ice crystals.

CLOUD SEEDING OF JUNE 22, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located in a south-to-north circulation east of a low pressure system centered in south-central Nebraska. Scattered showers were occurring or had occurred over Ohio and Indiana in the 6-hour period prior to 1330 E. S. T. The pressure was falling very slowly over the area of operations.

Conditions of seeding.—Cumulus clouds were seeded four times. On all runs the bases of the clouds were near 5,000 feet mean sea level, with temperatures of +20.0° C. The tops of the clouds were at 20,000 feet mean sea level on the first two seedings, with a temperature of −6.0° C.; 20,100 feet, with a temperature of −6.0° C. on the third run; and at 18,000 feet, with a temperature of −4.0° C. on the fourth run. The freezing level was almost at 16,400 feet mean sea level.

Rate of seeding.—Water spray was used on three of the seeding runs, and dry ice pellets ⅜ to ¾ inch in diameter were dropped on the third run at the rate of three pounds per mile. On the fourth seeding, a small amount of dry ice was also dropped with the water.

Time and duration of seeding:

1st seeding: 1344:48 E. S. T.; 1 minute and 27 seconds.
2d seeding: 1418:07 E. S. T.; 48 seconds.
3d seeding: 1437:37 E. S. T.; 53 seconds.
4th seeding: 1503:45 E. S. T.; 40 seconds.

Results.—A texture change and some dissipation of the seeded areas were observed after all four seedings. The first seeded cloud was changing to ice crystals at the time of seeding, but the seeding seemed to have increased the ice crystal texture of the cloud, and the top partially dissipated. The fourth seeding produced the greatest amount of dissipation, with the entire body of the cloud dissipating and leaving only thin veils of ice crystals.

The second cloud appeared as an echo on the radar scope in the aircraft before it was seeded. After the second seeding, a rainbow was observed below the seeded cloud, but it is not known whether or not the precipitation reached the ground. Since the cloud was already appearing as an echo on the radar scope, rain must have been falling from the cloud before it was seeded. No precipitation was observed to have fallen from the clouds after the other seeding runs.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Aerial observations (visual).
   b. 2d seeding: Aerial observations (visual) and radar pictures from plane.
   c. 3d seeding: Aerial observations (visual).
   d. 4th seeding: Aerial observations (visual) and visual observations of radar scope in airplane.

Comments.—Alternate building and dissipation were observed in various clouds close to the seeded areas. Dissipation was noted, however, in clouds that were observed to be building at the time of seeding.

After the first seeding, some dissipation in the seeded area was observed even though the cloud was changing to ice crystals and building slightly through natural processes. Since no icing of consequence was noted when the cloud was flown through on the seeding run, the supercooled water

content must have been very small; therefore, major changes should not have been expected.

After the third seeding, portions of the cloud that were not affected directly by seeding grew about 400 feet in the 2 to 3 minutes after seeding, while the seeding operation dissipated one of the bulges.

Because of radar difficulty, neither the seeding aircraft and the low observation plane nor the location of the seeded areas could be coordinated; therefore, it was impossible to determine whether the precipitation observed after the second seeding reached the ground. Visual observations made by the seeding aircraft indicated that the rain from the second seeding probably did not reach the ground. Furthermore, natural showers were occurring in the vicinity of all the seeded areas, thereby adding to the difficulty of definitely determining how much if any of the precipitation falling from the seeded cloud was the result of seeding.

CLOUD SEEDING OF JUNE 24, 1948

Synoptic situation.—At 1330 E. S. T., the area of seeding operations was located on the southern edge of a low pressure trough running east-west across southern Lake Superior to southern North Dakota. The pressure gradient was weak and the pressure was falling over the operations area. Scattered showers had occurred over Ohio and Indiana between 0630 and 1330 E. S. T. A squall line oriented north-south passed over the local area previous to the mission times. The seeding operations were conducted approximately 110 to 120 miles southeast of Jamestown, Ohio, and along the extreme southern end of the squall line.

Conditions of seeding.—Two cumulus clouds were seeded in three runs, with one run made on the first cloud and two on the second. The first cloud top was at approximately 19,000 feet mean sea level, the second at 18,000 feet, and the bases of both were at 5,200 feet. Temperatures of the first cloud were +18.0° C. at the base, −7.0° C. at the top; in the second, +18.0° C. at the base and −6.0° C. at the top. Some altostratus clouds were present also, with bases at about 14,000 feet mean sea level. The freezing level was at approximately 14,000 feet mean sea level. The third run was across the cloud, with the seeding performed in the towering tops on each end. The aircraft was in the first bulge about 9 seconds and in the second bulge about 10 seconds.

Rate of seeding.—Dry ice pellets were dropped at the rate of 4 pounds per mile on the first and third runs, 3 pounds per mile on the second run.

Time and duration of seeding:

1st seeding: 1126:55 E. S. T.; 30 seconds.
2d seeding: 1155:45 E. S. T.; 45 seconds.
3d seeding: 1201:36 E. S. T.; 54 seconds (19 seconds in cloud).

Results.—After the first seeding, a texture change was noted (fig. 23). The cloud echo that appeared on the radar scope in the aircraft prior to the seeding run split into two parts. The echo was also observed on the V-beam radar, and it finally disappeared from the scope. The cloud followed the same procedure and finally evaporated into thin veils (fig. 23 (d)). The second cloud also experienced a change in texture and the tower that was seeded on the first run dissipated, while a tower on each end of the cloud built up. The next run, through the two towers, caused a change in texture, and the cloud stopped growing and dissipated to some extent. The dissipation of this second cloud was not as marked as that observed in the first cloud.

A rainbow was observed below the first cloud after seeding, but since the cloud was already appearing as an echo on the radar scope, rain must have been falling from the cloud before it was seeded. No precipitation was observed to have fallen from the second cloud before or after seeding. There was no echo on the radar scope from the second cloud seeded.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual and photographic—fig. 23).
   b. 2d seeding: Aerial observations (visual and photographic).
   c. 3d seeding: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Aerial observations (visual) and pictures of radar scope in the airplane and visual observations of CPS–6 radar scope.
   b. 2d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.
   c. 3d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Since the first seeded cloud appeared as an echo on the radar scope prior to seeding, the positive precipitation results lacked significance. A low observation plane did not fly the mission because of mechanical failure, but observers in the seeding aircraft could observe the base of the second seeded cloud and they reported that no precipitation fell from the cloud before or after seeding. A small cloud echo was observed on the radar scope about 8 miles south of the second seeded area, and a small line of showers was observed about 20 miles west of the area before and after seeding.

Since other clouds, as well as the seeded clouds, were building at the time of seeding, the dissipation results observed may have been significant. Other clouds in the immediate vicinity of the seeded areas had built into the thunderstorm stage; therefore, the seeding may have prevented the clouds that were affected from developing into similar storms. Dissipation results and verification of the results were the best obtained to date on cumulus clouds.

CLOUD SEEDING OF JUNE 28, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located on the eastern side of a weak

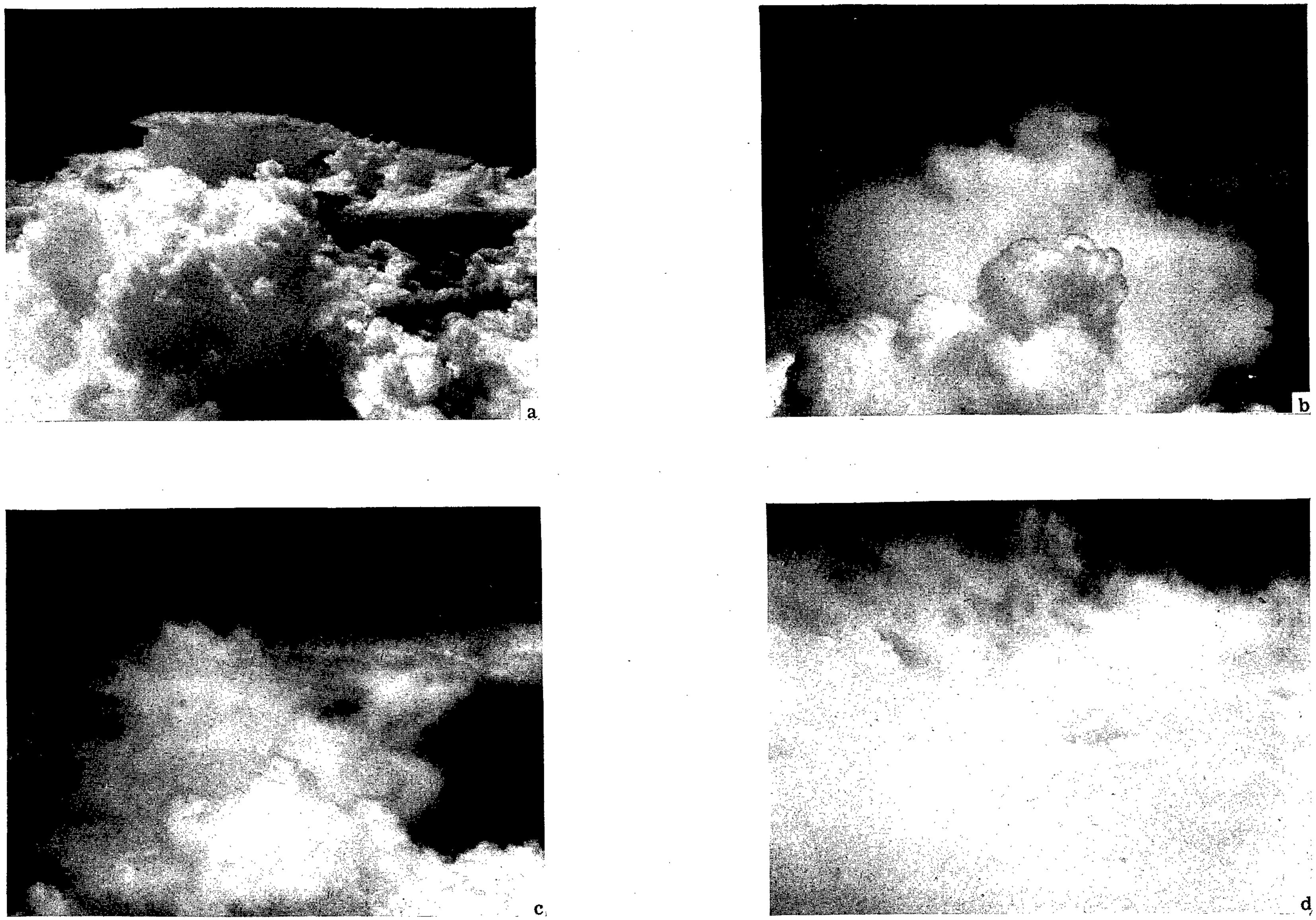


FIGURE 23.—Sequence of cloud pictures from first seeding run on June 24, 1948. (a) 1125 E.S.T. View of cloud to be seeded. (b) 1142 E. S. T. View of cloud approximately 15 minutes after seeding, showing difference in texture between seeded cloud (in background) and unseeded cloud (in foreground) which was observed to be building. (c) 1148 E. S. T. (d) 1150 E. S. T.

low pressure trough running from the southeastern part of Iowa across northwestern Missouri. The pressure was falling slowly on the eastern side of the trough line. A few showers were occurring or had occurred over southwestern Ohio and along the Indiana-Kentucky border between 0730 E. S.T. and 1330 E. S. T.

Conditions of seeding.—Three seeding runs were made, but only one run is considered in this report. The dry ice was accidentally dropped into the clear air between the clouds on the first run. The third run is omitted because there is some doubt as to whether or not the cloud was actually seeded. The cumulus cloud that was seeded on the second run was based at 6,000 feet mean sea level, with its top at about 18,500 feet. The temperature at the base was +16.0° C. and at the top, −8.0° C. The freezing level was approximately 13,600 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 7 pounds per mile.

Time and duration of seeding:

1st seeding: Not included.
2d seeding: 1430:25 E. S. T.; 45 seconds.
3d seeding: Not included.

Results.—The seeded cloud had a tower on each end of it and the cloud was building at the time of seeding. Both towers were seeded. After seeding, the top continued to build for almost 4 minutes; then it turned into thin veils of ice crystals and settled down to 17,000 feet mean sea level. Approximately 1,500 feet of the top dissipated.

Rain was observed to have fallen from the seeded cloud about 15 minutes after seeding, and an echo from the seeded area appeared on the radar scope at 1439 E. S. T., but it cannot be said definitely whether the echo was formed as a result of seeding or whether it would have formed naturally. The echo continued to grow until 1450 E. S. T., and then it began to decrease in size. It finally disappeared from the scope at 1509.

The seeded cloud did not pass over a rain gage, but the low observation plane reported moderate precipitation falling from the cloud. Precipitation from other clouds that formed an echo on the radar scope of about the same size and intensity as the seeded one produced as much as 0.22 inch of rainfall; therefore, it is likely that a similar amount fell from the seeded cloud, but it may not be said definitely how much, if any, of the rain may be attributed to the seeding operations.

Method of verification:

1. Structural:
   a. 2d seeding: Aerial observations (visual) and 16-mm. motion pictures of seeded cloud.
2. Precipitation:
   a. 2d seeding: aerial observations (visual) and photographs of CPS–6 radar scope.

Comments.—The dissipation observed may have been significant since the cloud was building at the time of seeding. The precipitation results may have been significant also, but other showers were developing and dissipating as close as 8 miles from the seeded area. For example, one echo appeared on the radar scope about 25 miles southwest of the seeded area and grew to about the same size, disappeared from the scope within about the same period of time. Therefore, since changes of about the same magnitude and rate were occurring naturally, definite conclusions of the precipitation results may not be drawn.

CLOUD SEEDING OF JUNE 29, 1948

Synoptic situation.—At 1330 E. S. T., the area of seeding operations was located east of a cold front running northeast to southwest across northwestern Indiana and southeastern Illinois. Scattered rain showers or thunderstorms had occurred over southwestern Ohio and over most of Indiana between 0730 E. S. T. and 1330 E. S. T. The pressure changes were quite diversified, with falls in pressure of about 1.8 mb. in the shower areas; but northwest of the cold front, the changes ranged from −0.2 mb. to +0.6 mb.

Conditions of seeding.—One cumulus cloud was seeded twice. It had two pronounced bulges. Each of the bulges was seeded. Light showers were indicated on the radar scope within 10 to 15 miles of the first seeded area. A thunderstorm with heavy precipitation and peak wind gusts of 75 m. p. h. passed over the Air Force base during the late morning. The tops of the seeded cloud varied from 16,900 feet mean sea level on the first run to 19,000 feet on the second. The bases were at about 3,500 feet on both runs. Low scud clouds based at 2,000 feet were observed in the seeded area also. Temperatures near the top of the cloud ranged from −0.5° C. on the first run to −8.0° C. on the second. Temperatures at the bases were +18.0° C. on both runs. The freezing level was near 13,400 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 12 and 20 pounds per mile, respectively, on the two seeding runs.

Time and duration of seeding:

1st seeding: 1503: 40 E. S. T.; 30 seconds.
2d seeding: 1520: 35 E. S. T.; 20 seconds.

Results.—Observed results of the first seeding were of a minor nature. A light texture change and a slight sinking of the top was observed. After the second seeding run into the second tower of the same cloud, a texture change was noted and a sinking of the top was observed. The final result of both seedings was the complete dissipation of both towers, leaving a stratiform appearance to the cloud.

A rainbow was observed (the best to date) under the seeded cloud after the second seeding run, but it could not be definitely determined whether or not the precipitation was the result of seeding. An airplane was vectored beneath the cloud a short time later, and the observers reported that the precipitation was light and did not reach the ground.

Method of verification:

1. Structural:
   Both seedings: Aerial observations (visual).
2. Precipitation:
   Both seedings: Aerial observations (visual) and pictures of the CPS–6 radar scope.

Comments.—The dissipation results observed may have been significant, since the cloud was noted to be building at the time of the first seeding run. While the bulge that was seeded the first time was slowly dissipating as a result of the seeding, the second bulge of the same cloud remained about the same until it was seeded. After the seeding of the second bulge, it began to dissipate also.

The precipitation results observed lacked significance, since the seeded cloud was already appearing as an echo on the radar scope before it was seeded—a possible indication that precipitation, even though it was not observed visually until after the second seeding, was falling from the cloud before it was seeded. It is possible that the seeding did hasten the dissipation of the cloud and prevent further development of the storm. Other shower echoes were forming within 30 miles of the seeded area at the time the echo from the seeded cloud was disappearing from the radar scope. This echo from the seeded cloud disappeared from the scope by 1531 E. S. T.

Only two airplanes flew the mission. The high photo plane was directed, after a rainbow was observed below the seeded cloud, to descend and investigate the intensity and amount of rain falling. Upon descent, observers reported that rainfall was light and did not reach the ground.

CLOUD SEEDING OF JUNE 30, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was located east of a cold front oriented northeast to southwest across the extreme northwestern part of Ohio and central Indiana. A thundershower was occurring at Columbus, Ohio, at map time, and several showers had occurred over southwestern Ohio prior to 1330 E. S. T.

Conditions of seeding.—Various portions of a cumulus cloud were seeded on three different runs. The cloud had two pronounced bulges; one of the bulges was seeded on the first run while the second bulge was seeded on the second and third runs. Another towering cumulus was just to the southwest of the seeded cloud. The tops of the cloud ranged from 18,000 feet mean sea level on the first run to 17,000 feet on the second, and 16,700 feet on the third; the base ranged from 3,500 feet on the first run to 4,800 feet on the second and third runs. Temperatures near the tops were $-10.0°$, $-7.0°$ and $-6.0°$ C., respectively, on the three runs, and temperatures at the bases were $+18.0°$ C. on the first run and $+15.0°$ C. on the second and third runs. The freezing level was at about 12,400 feet mean sea level. Light to moderate turbulence was encountered on the first seeding run, but none was observed above the cloud tops on the other two seedings.

Rate of seeding.—Dry ice pellets were dropped at the rate of 1, 10, and 15 pounds per mile respectively on the three runs.

Time and duration of seeding:

1st seeding: 1415:15 E. S. T.; 32 seconds.
2d seeding: 1504 E. S. T.; 32 seconds.
3d seeding: 1508:55 E. S. T.; 20 seconds.

Results.—Dissipation was observed after all three seedings. A trough formed in the first cloud, and the seeded area thinned out so much that the ground could be seen in spots, but a definite hole did not form. After the second seeding (the first run on the second tower), a small portion of the top dissipated. Following another run into the same portion of the cloud as the second run, the cloud dissipated rapidly, leaving a hole. A texture change was observed after the seeding runs.

A few drops of precipitation were observed to have fallen after the first seeding, but it cannot be definitely said that it was the result of seeding. No precipitation fell after the second and third seedings.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Aerial observations (visual), radar tracks of the aircraft, and rain gage at Clinton County Air Force Base (figs. 1 through 6).
   b. 2d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope (figs. 7 and 8).
   c. 3d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Dissipation results may have been significant, since the cloud was observed to be building at the time of seeding. The sequence of events, as correlated from visual observations and radar pictures would indicate that some natural dissipation aided the artificial process. For instance, the indications were that a light shower occurred under the second bulge before it occurred under the first bulge; and then at the time of seeding the second bulge, it was observed to be stagnant—a possible indication that its energy had been spent and artifical plus natural dissipation affected that portion of the cloud. The cloud echo on the radar scope had also disappeared by the time the second bulge was seeded, but an echo from a cloud a short distance southwest of the seeded cloud still remained.

Precipitation observed after the first seeding may have been significant, but, since the indications were that the shower started in a portion of the cloud that was not affected directly by seeding and which continued to build, it cannot be said definitely whether the rain would have occurred without the seeding operation or not. An echo from a second cloud (not seeded) continued to

grow until 1508 E. S. T. and then disappeared from the scope by 1528 E. S. T. (figs. 7 and 8).

CLOUD SEEDING OF JULY 7, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located on the southern side of an anticyclone centered in Canada. Skies were mostly broken over southern Ohio, with stratocumuli and a few towering cumuli present. There were no fronts in the immediate vicinity of the operations area. Pressure changes indicated a very slow increase of pressure over the area.

Conditions of seeding.—Two small cumulus clouds were seeded. The first cloud was seeded twice, the second cloud once. Tops of the cloud were at 7,400, 8,000, and 8,900 feet mean sea level, respectively, on the three runs; the bases ranged from 4,800 feet on the first run to 5,300 feet on the last two. Temperatures were +8.0°, +6.0°, and +8.0° C., respectively, in the vicinity of the tops of the clouds; at the bases they were +14° C. on the first run and +13.0° C. on the last two runs. Scattered altostratus clouds were present also, based at 15,000 feet. The freezing level was at about 15,200 feet mean sea level.

Rate of seeding.—Water was sprayed into the clouds on all three seeding runs.

Time and duration of seeding:

1st seeding: 1357 E. S. T.; 1 minute.
2d seeding: 1415 E. S. T.; 30 seconds.
3d seeding: 1446 E. S. T.; 1 minute.

Results.—After the first seeding, the top of the cloud rose from 7,400 feet to 8,000 feet mean sea level, and a faint seeding path was visible. The second run into the same cloud caused it to flatten out, and the density changed so much that the observers in the high photo plane could see through the cloud. After the third seeding, a run on another cloud, a hole formed in it and observers could see the ground through it. About 15 to 20 minutes after seeding, the hole began to fill again.

Precipitation results observed were negative after all three seeding runs.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual). (Note: Pictures were taken, but they did not show the results that were observed visually.)
2. Precipitation:
   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Effects of dissipation were observed in the seeded area even though the cloud was building slightly at the time of seeding. The temperature sounding, however, indicated that the clouds had just about reached their maximum height since their tops were extending into an area in which the vertical currents would have been damped out. Even though building was observed after the first seeding, it must be noted that the cloud was building slightly at the time it was seeded.

The environment in the vicinity of the cloud indicated that its vertical development would be hindered and the cloud could not grow to an appreciable size; therefore, a significant amount of precipitation should not have been expected. There were no showers occurring naturally in the vicinity of the seeded area.

CLOUD SEEDING OF JULY 9, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located on the western edge of an anticyclone centered off the central Atlantic coast. A squall line was to the west of the seeding area running north-to-south through Iowa and northwestern Missouri. Various amounts of cumulus and stratocumulus clouds covered southwestern Ohio.

Conditions of seeding—Three cumulus clouds were seeded, the first four times and the others once each. The tops of the clouds were at 11,900, 11,900, and 24,500 feet mean sea level, respectively, and their bases were at 5,200 feet. The temperatures at the tops ranged from +4.0° C. on the first two clouds to −23.0° C. on the third cloud; at the bases temperatures were +18.0° C. on all seeding runs. The freezing level was at about 14,200 feet mean sea level. Light turbulence was encountered in the first two clouds, and moderate turbulence was observed in the third cloud on the seeding runs.

Rate of seeding.—The water spray was used on the first four drops into the first cloud. Dry ice pellets were dropped in the second and third clouds at the rate of 15 and 12 pounds per mile, respectively. Water was also sprayed into the second and third clouds.

Time and duration of seeding:

1st to 4th seedings: 1502:30 E. S. T.; 11 minutes and 12 seconds.
5th seeding: 1526:15 E. S. T.; 30 seconds.
6th seeding: 1554:40 E. S. T.; 20 seconds.

Results.—Each time a run was made on the first cloud a portion of the top dissipated; finally, after the fourth run, one end of the cloud dissipated. After the seeding of the second cloud, it began to dissipate rapidly and a hole formed through it. Following the seeding of the third cloud (the sixth run), the top seemed to break off from the base, with about 200 to 500 feet of the top section dissipating (fig. 24). Moderate turbulence was observed in and around the cloud before seeding, but on a run through it a few minutes later the air was observed to be smooth.

A few drops of rain were observed below the second cloud after seeding, but the rain was not believed to have reached the ground. Light rain was also observed within 5 miles of the third seeded area (about 31 minutes after seeding), but it could not be determined definitely whether or not it was the result of seeding.

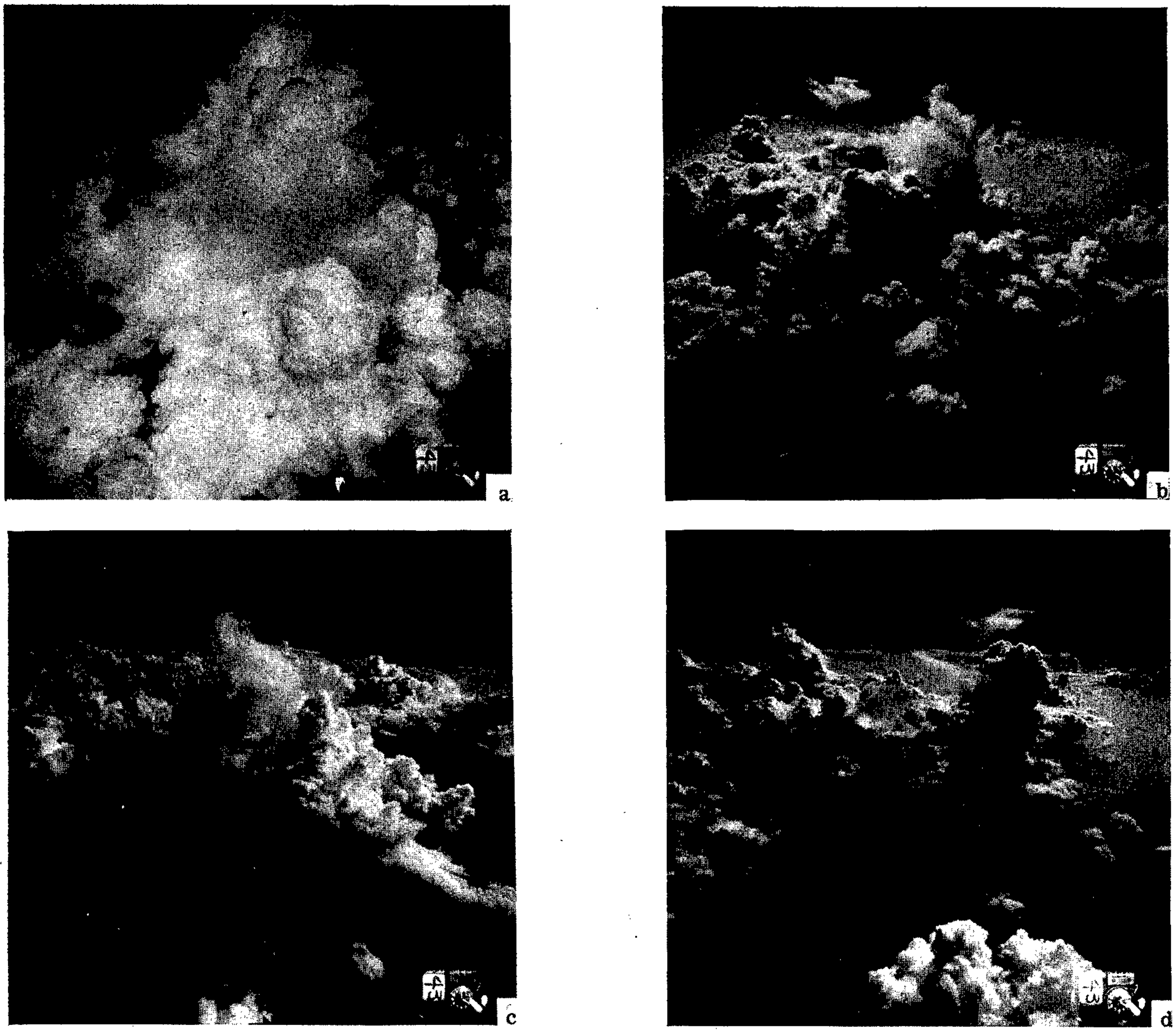


FIGURE 24.—Sequence of cloud pictures from sixth run of July 9, 1948. (a) 1552:30 E. S. T. View of third cloud to be seeded, observed to be building at the rate of about 500 feet per minute at the time of seeding. (b) 1556:45 E. S. T. View of cloud approximately 2 minutes after seeding. (c) 1600:15 E. S. T. View of cloud about 6 minutes after seeding, showing contrast with unseeded cloud (to the right), which was building (see cloud at right in (b)). (d) 1608:15 E. S. T. View of remaining portion of cloud after about 200 to 500 feet of the top section had dissipated.

Method of verification:

1. Structural:
   a. 1st to 4th seedings: Aerial observations (visual and photographic).
   b. 5th and 6th seedings: Aerial observations (visual and photographic). (fig. 24)
2. Precipitation:
   All seedings: Aerial observations (visual).

Comments.—The V-beam radar was inoperative throughout the entire mission. Locations of seeded areas by the various aircraft could be made only through visual references made by the observers in the aircraft.

Dissipation results were observed in the first two clouds, that were stagnant at the time of seeding, and in the third cloud which was building at the rate of about 500 feet per minute at the time of seeding. It is interesting to note that no clear ice was picked up at the seeding altitude when the run was made through the third cloud. This cloud was already forming a veil top and the seeding aircraft picked up only snowflakes on the run; yet some dissipation was observed below the seeding level, with the top portion of the cloud being cut off from the base, thereby possibly indicating supercooled water droplets below the seeding level. It may be emphasized that water and dry ice were used simultaneously on the second and third clouds; therefore, it was impossible to determine which of the nucleating agents was responsible for the results observed.

The precipitation observed may or may not have been significant. At any rate, no measurable amounts of rainfall were observed; therefore, if any rain did fall as a result of the seeding, it was

inconsequential economically. Natural showers were occurring within 30 miles of the third seeded cloud and within 60 to 70 miles of the second seeded cloud.

It was also noted that a portion of the third cloud began to build again a short time after the dissipation of the seeded portion was observed. This may or may not have been the result of seeding. The precipitation could have been caused indirectly by seeding also, but definite conclusions in this regard may not be drawn.

CLOUD SEEDING OF JULY 12, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was in a very weak and indefinite pressure field. There was considerable cloudiness over Ohio, Indiana, and northern Kentucky, with scattered showers and thunderstorms over the area.

Conditions of seeding.—Three cumulus clouds were seeded. The first two clouds were already producing showers at the time of seeding; the third cloud was small and no rain was falling from it, but showers were occurring about 30 miles south of it. The tops of the clouds ranged from 19,500 feet mean sea level on the first run, to 20,000 feet on the second run, and 7,000 feet on the third run. Bases were near 3,800 feet, with a temperature of $+20.0°$ C. Temperatures in the vicinity of the tops were $-8.0°$, $-9.0°$, and $+14.0°$ C., respectively, on the three runs.

Rate of seeding.—Dry ice pellets were dropped into the clouds on the first two seeding runs at the rate of about 8 pounds per mile. Although the duration of seeding in the second cloud was not known, the time was estimated in order to arrive at the rate of seeding. Water was sprayed into the third cloud.

Time and duration of seeding:

1st seeding: 1414:15 E. S. T.; 45 seconds.
2d seeding: 1448:30 E. S. T.; actual time not determined.
3d seeding: 1521:50 E. S. T.; 30 seconds.

Results.—After the first seeding, the cloud stopped building and about three-fourths of it dissipated, with a trough forming. Following the second seeding, about 50 percent of the cloud dissipated. A change in texture was observed after the first and second seedings. No results were observed after the third seeding.

Rain was falling from the first two clouds and echoes from them were present on the radar scope before and after seeding. No rain was observed to have fallen from the third cloud.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual). (Note: Pictures taken were overexposed.)
2. Precipitation:
   a. 1st seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.
   b. 2d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope. Also, rain gage measurements from several stations in the southeast portion of the Cloud Physics rain gage network.
   c. 3d seeding: Aerial observations (visual) and visual observations of the CPS–6 radar scope.

Comments.—The dissipation results observed after the first two seedings were noted in clouds that were building at the time of seeding. The divergence of results in reference to the change in the size of the rain echoes on the radar scope may have been significant. For example, the echo from the first area seeded decreased in size, while echoes from unseeded portions actually merged together and increased in size, but the sequence of events reversed after the second seeding An echo very close to the second seeded area decreased in size much more rapidly than the echo from the seeded area.

There was no dissipation observed after the third seeding even though the cloud was observed to be stagnant at the time of seeding. This cloud was seeded with water.

Rainfall observed after the first and second seedings was not significant, since rain was falling from the clouds before they were seeded. Even though there was no precipitation from the third cloud, it must be noted that the cloud was small and could not have produced a significant amount of rain, even through natural processes, without considerable propagation. The first cloud did not pass over a rain gage; but since it formed an echo about the same size as the second cloud, it was estimated that about 0.11 inch of rain fell from it. The second cloud passed over the rain-gage network, and a maximum of 0.11 inch of rainfall was recorded at Station No. 50 for the period 1505 E. S. T. to 1515 E. S. T.

CLOUD SEEDING OF JULY 13, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was south of a cold front running east-west across central Ohio and Indiana. Pressure tendencies on both sides of the front indicated that it would be very slow-moving. Considerable cloudiness covered Ohio and Indiana, with towering cumulus prevalent over southwestern Ohio.

Conditions of seeding.—Five cumulus clouds were seeded on four runs. On the second run, two clouds that were oriented in a north-south line were seeded consecutively. Some altostratus clouds were present, and occasionally the seeding aircraft observed very light rain falling from that cloud deck. Tops of the clouds ranged from 13,000 feet mean sea level to 13,300 feet on the first two runs and 17,000 feet on the last two runs, which were on the same cloud. Bases were near 5,000 feet mean sea level, with temperatures of $+17.0°$ C. Temperatures in the vicinity of the

cloud tops were +3.0°, +2.0°, −4.0°, and −4.0° C., respectively, on the four seeding runs.

Rate of seeding.—Water was sprayed into the clouds on the first two runs, and dry ice was dropped in the cloud at the rate of 12 and 17 pounds per mile on the last two seedings.

Time and duration of seeding:

1st seeding: 1422:05 E. S. T.; 25 seconds.

2d seeding: 1445:30 E. S. T.; 1 minute. (Water was left on while the aircraft was in the clear air between the two clouds seeded.)

3d seeding: 1516:47 E. S. T.; 38 seconds.

4th seeding: 1524:25 E. S. T.; 30 seconds.

Results.—After the first seeding, there was a slight change in density followed by a sinking of the cloud top. About 9 minutes after seeding, the cloud had shrunk so much that only a small portion of it remained. Following the second seeding of two clouds very close together the first one dissipated within 1 minute and the other cloud persisted for about 10 minutes and built up slightly. Then the second cloud began to dissipate, with a hole forming in it. Final observations revealed that about 90 percent of the cloud dissipated. Following the third run, the cloud began to dissipate; and after another run into the same cloud, a hole formed through the cloud, allowing the observers to see the ground.

Very light precipitation was observed below the second cloud of the second seeding, but observers reported that it did not reach the ground. Following the third seeding, a small echo appeared on the radar scope at 1522 E. S. T., and light rain was observed below the cloud for the first time at 1525:50 E. S. T. No precipitation was observed to have fallen from the first cloud seeded.

Method of verification:

1. Structural
   a. 1st seeding: Aerial observations (visual) and pictures of seeded cloud.
   b. 2d seeding: Aerial observations (visual) and pictures of seeded clouds, showing partial results on the second cloud.
   c. 3d and 4th seedings: Aerial observations (visual).
2. Precipitation:
   a. 1st three seedings: Aerial observations (visual) and photographs of CPS–6 radar scope.
   b. 4th seeding: Aerial observation (visual) and photographs of CPS–6 radar scope plus visual observations by surface observer.

   (Note: Pictures taken of the base of the clouds on the 2d, 3d, and 4th seedings, but precipitation was too light to show.)

Comments.—Dissipation was observed in clouds that were building at the time of seeding.

Other showers were occurring within 15 miles of all the areas seeded. Observations of the radar scope indicated that the echo formed after the third seeding probably did not grow to full size, because its maximum size was very insignificant in comparison with natural echoes that were forming and growing at the same time very close to the echo from the seeded area. One echo about 15 miles southwest of the seeded cloud formed after the one which followed seeding and grew to be considerably larger than the maximum size of the echo from seeding. Such a sequence of events may have been significant. Precipitation from the seeded cloud was observed by the surface observer at Station No. 19 of the rain gage network from 1530:10 E. S. T. to 1537 E. S. T. The total amount of rainfall that fell from the cloud was only a trace.

CLOUD SEEDING OF JULY 16, 1948

Synoptic situation.—The seeded area at 1330 E. S. T. was located in the warm sector of a low-pressure area. The warm front was oriented north-south through eastern Ohio, and the cold front was oriented north-south through eastern Illinois. Pressure changes were small and of about the same magnitude on both sides of the cold front. Skies were cloudy, and scattered showers and thundershowers were occurring or had occurred over southwestern Ohio.

Conditions of seeding.—Two cumulus clouds were seeded, and one run was made through a cloud without the dropping of any nucleating material, in order to determine the effect of the aircraft on the cloud. Since results of that run were insignificant, they have been omitted from this report. The third seeding was into the same cloud on which the dry run was made. Tops of the clouds ranged from 13,000 feet mean sea level, with a temperature in the vicinity of the tops of +5.0° C. on the first run, to 15,000 feet with a temperature of +1.0° C. on the third. Bases were near 4,500 feet with temperatures of +19.0° C. Some scud clouds were present at 300 to 400 feet as well as some altocumuli. Several showers were occurring close to the seeded areas on all runs. The freezing level was at approximately 15,800 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 5 pounds per mile on the first and third seeding runs.

Time and duration of seeding:

1st seeding: 1454:35 E. S. T. 27 seconds.

2d seeding: Not included in this report.

3d seeding: 1528:05 E. S. T.; 1 minute and 15 seconds.

Results.—After the first seeding, about 90 percent of the cloud dissipated. Only the low scud clouds below the main body of the cloud were left. Following the third seeding, about 50 percent of the cloud dissipated; the top portion disappeared.

Rain was observed to have fallen from the first seeded cloud before and after seeding. Observers in the low observation plane estimated that the

rain was falling to the ground. Rain was observed in the third cloud on the seeding run; therefore, a light rain probably was falling or on the verge of falling at the time of seeding. A cloud echo, however, did not appear on the radar scope until 2 minutes after seeding.

Method of verification:

1. Structural:
   - a. 1st seeding: Aerial observations (visual) and photographs of seeded cloud.
   - b. 2d seeding: Not included in this report.
   - c. 3d seeding: Aerial observations (visual).
2. Precipitation:
   - a. 1st seeding: Aerial observations (visual) and pictures of CPS–6 radar scope. Rain gage reports from Cloud Physics surface network.
   - b. 2d seeding: Not included.
   - c. 3d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope. Did not pass over a rain gage.

Comments.—Dissipation was observed in clouds that were building at the time of seeding. To add further significance to the results, dry ice was used even though the temperatures of the clouds were above freezing.

It was significant that light rain was falling naturally from the clouds seeded, even though it was indicated that their temperatures were above freezing. The first seeded area passed over the surface network, but no rain was recorded by the rain gages. (Note: It requires about 0.01 inch of water to affect the weighing-type rain gage.) Natural showers that were moving across the network about 6 miles to the northwest of the seeded area produced about 0.08 inch of rain.

Another significant point was revealed when a small echo appeared in the third seeded area about two minutes after seeding. It did not grow to an appreciable size, but it dissipated within 10 minutes while a cloud within 3 miles of the seeded one formed an echo that persisted and grew in size. The echo from the unseeded cloud was still present on the radar scope at 1548 E. S. T., when the cameras were turned off. Since considerable moisture and light rain were encountered in the third cloud on the seeding run, the indications were that the cloud might have produced a light rain regardless of whether or not it was seeded.

Because of difficulty in locating the low observation plane on the radar scope, it was not used on the third seeding; therefore, it could not be definitely determined whether rain was actually falling from the cloud before seeding.

CLOUD SEEDING OF JULY 19, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was located in a weak pressure field south of a cold front oriented east-west across extreme northwestern Ohio and thence southwest through central Indiana. A shower was reported at map time at Clinton County Air Force Base, and thundershower activity was occurring along a squall line running north-south through central Illinois.

Conditions of seeding.—Three cumulus clouds were seeded on four runs. The second and third runs were made into a cumulus that had already developed into a thunderstorm. Because of the confusion in trying to follow the seeded cloud, observations were inaccurate and the cloud was abandoned; therefore, it is not included in this report. The tops of the clouds on the first and fourth runs were 13,700 feet mean sea level and 16,500 feet, respectively, with temperatures in the vicinity of the tops +1.0° C. on the first run and −2.0° C. on the fourth. Bases were at 4,000 feet mean sea level, with temperatures of +18.0° C. The freezing level, according to the adiabatic chart, was near 14,000 feet mean sea level.

Rate of seeding.—Water was sprayed into the clouds on all seeding runs. Charged water was used on the fourth run.

Time and duration of seeding:

1st seeding: 1503:05 E. S. T.; 30 seconds.
2d seeding: 1512:37 E. S. T., not included.
3d seeding: 1515:30 E. S. T.; not included.
4th seeding: 1538:20 E. S. T.; 1 minute and 20 seconds.

Results.—After seeding of the first cloud, it completely dissipated, but observations revealed that it was dissipating at the time of seeding. After the fourth seeding, about 20 percent of the cloud dissipated.

No precipitation was observed to have fallen from either of the clouds before or after seeding.

Method of verification:

1. Structural:
   - a. 1st seeding: Aerial observations (visual).
   - b. 4th seeding: Aerial observations (visual) and pictures of the seeded cloud.
2. Precipitation:
   1st and 4th seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Dissipation of the first cloud was not significant since it was dissipating naturally at the time of seeding. Other clouds in the vicinity of the seeded cloud were in various stages of development from dissipation to building. Dissipation results observed after the fourth seeding were in a cloud that was building at the time of seeding. Moderate to heavy turbulence was encountered in the cloud on the seeding run. A pronounced downdraft was observed in a portion of the cloud.

Natural showers were occurring within 15 miles of the first area seeded and within 10 miles of the 4th area seeded, but no showers fell from the seeded clouds before or after seeding.

CLOUD SEEDING OF JULY 27, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was southeast of a frontal system running northeast to southwest across southern Lake Michigan and northern Illinois. Wilmington, Ohio, was reporting a thundershower at map time.

Conditions of seeding.—Four runs were made on cumulus clouds, but only three are considered in this report. On the third run, the cloud dissipated before it could be seeded. The tops of the clouds ranged from 10,000 feet mean sea level to 12,300 feet, with temperatures near the tops ranging from +7.0° to +3.0° C. Bases were near 4,400 feet mean sea level, with temperatures of +17.0° C. The freezing level was at approximately 14,200 feet mean sea level.

Rate of seeding.—Water was sprayed into the cloud on the first run. The plane was flown through the cloud on the second run, but no seeding material was dropped. On the fourth run, dry ice was dropped at the rate of 4 pounds per mile.

Time and duration of seeding:

1st seeding: 1426:10 E. S. T.; 20 seconds.
2d seeding: 1434:40 E. S. T.; duration unknown.
3d seeding: cloud dissipated before it could be seeded.
4th seeding: 1457:25 E. S. T.; 15 seconds.

Results.—All clouds dissipated rapidly after seeding, but it is doubtful whether the dissipation was the result of seeding.

No precipitation was observed in or around the seeded areas.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual).
2. Precipitation:
   All seedings: Aerial observations (visual) and CPS–6 radar pictures.

Comments.—The observations of dissipation were not significant, since other clouds were dissipating naturally. At the time of the fourth seeding, another cloud very close to the seeded one dissipated as well as the seeded cloud. The cloud that was to be seeded on the third run dissipated naturally before the aircraft could be brought into position to drop the nucleating agent.

CLOUD SEEDING OF JULY 30, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was located east of a slowly moving cold front running northeast to southwest across northwestern Ohio and central Indiana. Towering cumulus clouds were predominant ahead of the front, with scattered showers along the cold front.

Conditions of seeding.—Four seedings runs were made, but only three are included in this report. The observers did not remain in the seeded area after the fourth run because of threatening weather at the airbase. Part of the seeding nuclei missed the first cloud. The tops of the clouds were at 13,200 feet mean sea level, 14,900 feet, and 16,500 feet, respectively on the three runs, with temperatures in the vicinity of +4.0°, +2.0°, and 0.0° C., respectively. Bases were near 4,550 feet, 3,700 feet, and 3,500 feet, with temperatures of +20.0°, +24.0°, and +25.0° C., respectively. The freezing level was near 16,500 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 7, 6, and 6 pounds per mile, respectively, on the three runs. All drops were made from above the cloud tops.

Time and duration of seeding:

1st seeding: 1422:15 E. S. T.; 1 minute and 8 seconds.
2d seeding: 1434:40 E. S. T.; 40 seconds.
3d seeding: 1459:30 E. S. T.; 1 minute and 5 seconds.
4th seeding: Not included.

Results.—After the first seeding, the top of the cloud stopped its growth, and about 20 percent of it dissipated. Following the second seeding, about 95 percent of the cloud dissipated, with the cloud breaking up into small pieces. The portion of the third cloud that was seeded began to dissipate after seeding, with the cloud splitting into two separate parts. The unseeded portion remained at about the same height as it was at the time of the seeding run.

No precipitation was observed below the clouds after the first and second seedings. Light rain was reported below a portion of the third cloud, but that area was appearing as an echo on the radar scope before the cloud was seeded (figs. 16, 17). Observers in the seeding aircraft observed a rainbow below the cloud after seeding.

Method of verification:

1. Structural:
   All seedings: Aerial observations (visual).
2. Precipitation:
   All seedings: Aerial observations (visual) and track of aircraft on CPS–6 radar scope (figs. 16 to 19).

Comments.—All clouds seeded were in the building stage while neighboring clouds were in stages varying from dissipation to building. Dry ice was used as the seeding agent even though the clouds were not supercooled.

The third cloud appeared as an echo on the radar scope about 10 minutes prior to the seeding run (fig. 16). The low observation plane did not report rain below the cloud, however, until 4 minutes after seeding. The rain fell from the portion of the cloud that was not seeded—under the tallest bulge. Since an echo was already present, the cloud probably would have produced light rain regardless of whether or not it had been seeded. The echo disappeared from the radar scope about 1504:30 E. S. T. The cloud did not pass over a rain gage.

Echoes of varying degrees of intensity were present within 12 to 15 miles of all the seeded areas.

CLOUD SEEDING OF AUGUST 5, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was located on the eastern side of an anticyclone. The clouds were mostly broken stratocumuli, with a few towering cumuli over southwestern Ohio. Scattered showers had occurred over southwestern Ohio during the 6-hour period preceding map time.

Conditions of seeding.—Cumulus clouds were seeded three times. The third cloud had two bulges that were seeded consecutively. The tops of the clouds were at 12,980 feet mean sea level, 13,080 feet, and 13,040 feet, respectively, with temperatures in the vicinities of the tops at −4.0°. Bases varied from 4,000 feet mean sea level to 4,500 feet, with temperatures of +13.0° to +12.0° C. Light to moderate turbulence was encountered in the clouds. The freezing level was near 10,200 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped on the first seeding run at the rate of 6 pounds per mile. Dry ice pellets were dropped in a lump drop on the second run, and water was sprayed into the cloud on the third run.

Time and duration of seeding.

1st seeding: 1440:20 E. S. T. 38 seconds.
2d seeding: 1508:15 E. S. T. 5 seconds.
3d seeding: 1535:20 E. S. T. 1 minute and 50 seconds.

Results.—After the first seeding run, the top of the cloud continued to build about 500 feet; then there was a texture change and the top and the base of the cloud began to dissipate. It became wispy with a hole forming through it. Final observations revealed that about 75 percent of the cloud dissipated. The top of the second cloud dissipated so rapidly that it was gone by the time the airplane had been turned 180°. There was only about 15 percent dissipation, however. About 10 minutes after seeding, the entire third cloud began to break up, with the top dropping and the base deteriorating. A hole finally formed through the cloud, with about 30 percent of the entire cloud body dissipating.

A few drops of rain were reported by the observer in the low observation plane about 11 minutes after the first seeding. A small faint cloud echo appeared on the radar scope approximately 20 minutes after the seeding run. No precipitation was observed before or after seeding in the second and third seeded areas.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual) and photographs of the seeded cloud.
   b. 2d seeding: Aerial observations (visual).
   c. 3d seeding: Aerial observations (visual) and photographs of the seeded cloud.
2. Precipitation:
   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—All clouds that were seeded were observed to be building at the time of seeding. Other clouds close by were in various stages, ranging from dissipation to building.

The precipitation observed after the first seeding run was very light and was not believed to have reached the ground. There were other cloud echoes within 30 miles of all the seeded areas. One small echo formed naturally at 1439 E. S. T. about 8 miles south of the area seeded on the first run. The natural echo disappeared from the radar scope at 1454 E. S. T. The echo from the seeded cloud appeared at 1500 E. S. T. and disappeared at 1507:25 E. S. T.

CLOUD SEEDING OF AUGUST 11, 1948

Synoptic situation.—The seeding area at 1330 E. S. T. was ahead of a cold front running northeast to southwest from northwestern Indiana through central Illinois. Stratocumuli and towering cumuli were the predominant cloud types over southwestern Ohio. A few scattered showers had occurred over central and southwestern Ohio in the 6-hour period prior to 1330 E. S. T.

Conditions of seeding.—Several cumulus clouds were seeded on four seeding runs. The first seeded cloud became confused with neighboring clouds, and since accurate observations could not be made, it is omitted from this report. The second seeding was in a cumulus cloud on the southwest end of a line of four. The third run was through the entire line which included another portion of the cloud seeded on the second run plus three additional clouds. The top of the cloud on the second run was at 13,620 feet mean sea level, with a temperature in the vicinity of the top of 0.0° C. The tops of the other clouds on the third run averaged 11,830 feet in height, with a temperature in the vicinity of the tops of +3.0° C. The top of the cloud on the fourth run was at 11,000 feet, with a temperature near the top of +5.0° C. The bases of all the clouds were near 3,000 feet mean sea level, with a temperature of +17.0° C. The freezing level was near 13,620 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 8 pounds per mile on the second run. Water was sprayed into the clouds on the third run. Lead oxide vapor was seeded into the cloud on the fourth run.

Time and duration of seeding:

1st seeding: Not included.
2d seeding: 1352:20 E. S. T.; 35 seconds.
3d seeding: 1406:02 E. S. T.; 2 minutes and 6 seconds.
4th seeding: Time and duration unknown.

Results.—After the second seeding, which was into only a portion of the cloud, there was a density change, with about 40 percent of the cloud

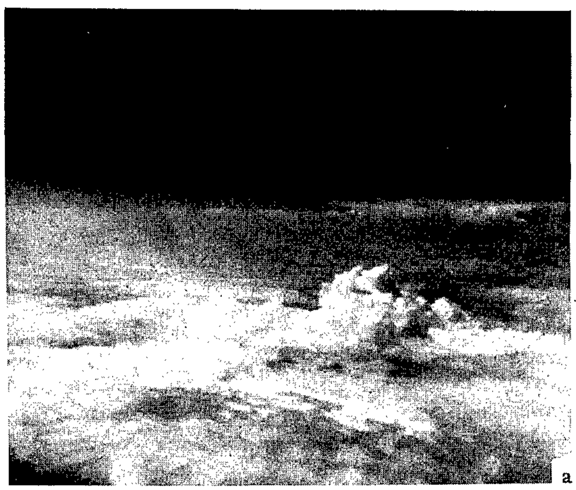
dissipating. A hole formed through the cloud in the seeded area (fig. 25). The unseeded portion of the cloud built up slightly. The third seeding run resulted in some dissipation of the tops of the first two clouds on the southwest end of the line. The other two clouds did not change much, but they merged together and the resulting top appeared to be about the same as the two tops had been before seeding except for a small amount of building. After the fourth seeding, a definite shallow trough appeared in the cloud, but it was not conclusive that such a result was due to the seeding alone.

Light rain was observed in the third seeded area before and after seeding. No precipitation was observed to have fallen after the second run. Results of precipitation after the fourth run were not determined, but there were no cloud echoes on the radar scope in or around the area in which the seeding aircraft circled.

Method of verification:

1. Structural:
   a. 1st seeding: Not included.
   b. 2d seeding: Aerial observations (visual) and photographs of seeded cloud (fig. 25).
   c. 3d and 4th seedings: Aerial observations (visual).
2. Precipitation:
   a. 1st seeding: Not included.
   b. 2d and 3d seedings: Aerial observations (visual) and positions of aircraft on CPS-6 radar scope.
   c. 4th seeding: Aerial observations (visual).

Comments.—Dissipation results were observed in clouds that were building at the time of seeding. Since the seeding altitude on the third run resulted in the aircraft's passing through some of the clouds and above the tops of others, it cannot be said just how much effect the aircraft may have had on the clouds in addition to the seeding material. After the fourth run, another cloud top was flown through to try to determine whether the trough formed in the cloud after seeding was the result of seeding or the result of the aircraft flying through the cloud. Some dissipation of the top of the unseeded cloud was also observed; therefore, it



a

b

c

FIGURE 25.—Sequence of cloud pictures from second seeding run of August 11, 1948. (a) View of cloud to be seeded. (b) View of cloud after seeding. (c) Later view of cloud after seeding, showing hole (in foreground) resulting from dissipation.

cannot be said how much of the results after the fourth seeding was due to seeding.

All indications were that the second cloud from the southwest end of the seeding line on the third seeding run was producing light rain before and after seeding. Aerial observations revealed that the rain was not striking the ground. No other precipitation was observed along the seeded line before or after seeding. The cloud echo from the second cloud appeared on the radar scope about 3 minutes after the second seeding run and disappeared 32 minutes after its inception. Whether the seeding had any direct effect on its disappearance cannot be said definitely, but another echo about 10 miles southeast of the seeded area went through a similar cycle within the same period of time. Natural showers were occurring within 12 to 15 miles of all the seeded areas. The seeded area did not pass over a rain gage.

CLOUD SEEDING OF AUGUST 13, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was in a weak and indefinite pressure field. A very weak stationary front was oriented east-west between Dayton, Ohio, and Wilmington, Ohio. Only scattered fair-weather type cumulus clouds with a few cirrus clouds were present over southwestern Ohio at map time.

Conditions of seeding.—Cumulus clouds were seeded five times. The third and fourth runs were into the same cloud. On the second seeding run, two bulges were seeded consecutively. The top of the first cloud was at 15,000 feet mean sea level, and the other three clouds ranged in height from 15,300 feet to 14,000 feet. Temperatures in the vicinities of the tops were $-2.0°$ C. on the first two runs and $-1.0°$ C. on the last three. Bases of the clouds were near 6,000 feet mean sea level, with temperatures of $+14.0°$ C. The freezing level was near 13,700 feet. Varying amounts of turbulence ranging from light to moderate were encountered in all clouds.

Rate of seeding.—Dry ice was dropped on the first two seeding runs at the rate of 6 pounds and 5 pounds per mile, respectively. Forty pounds of granulated dry ice were dumped into the cloud on the fifth run, instantaneously. Water was sprayed into the cloud on the third and fourth runs.

Time and duration of seeding:

1st seeding: 1354:15 E. S. T.; 45 seconds.
2d seeding: 1408:30 E. S. T.; 45 seconds.
3d seeding: 1442:45 E. S. T.; 1 minute.
4th seeding: 1445:45 E. S. T.; 50 seconds.
5th seeding: 1515:35 E. S. T.; 20 seconds.

Results.—The first seeding resulted in about 90 percent of the cloud dissipating in about 10 to 20 minutes after seeding. Following the second seeding, the cloud dissipated about 90 percent also. Both the first and second clouds seemed to fall to pieces, with numerous holes appearing in the clouds. After the third seeding, the seeding path was visible in the bulge seeded, with slight dissipation observed. Another portion of the cloud built up at the time the seeded portion was dissipating. The fourth run was into the section of the same cloud that had continued to grow vertically. Following this seeding, the entire cloud stopped its growth, with a density change and some dissipation observed in the entire cloud. The dissipation was not as marked as in the first two clouds. The fifth seeding resulted in about 85 to 90 percent of the cloud dissipating, but it is doubtful that the magnitude of the dissipation was the result of seeding alone.

The precipitation results were not accurately determined, but if any rain did fall from the clouds, it must have been light and insignificant because there were no echoes formed on the radar scope in the seeded area.

Method of verification:

1. Structural:
   a. 1st and 2d seedings: Aerial observations (visual) and photographs of seeded cloud.
   b. 3d seeding: Aerial observations (visual).
   c. 4th and 5th seeding: Aerial observations (visual) and photographs of seeded cloud.
2. Precipitation:
   a. 1st seeding: Pictures of CPS–6 radar scope, indicating no cloud echoes, and visual observations of radar scope at time of mission.
   b. Other seedings: Aerial observations (visual) and pictures of CPS–6 radar scope plus visual observations of radar scope at time of mission.

Comments.—The first two clouds in which dissipation was observed were about stagnant at the time of seeding. The cloud seeded on the third and fourth runs was observed to be in the building stage. The fifth cloud was predominantly stagnant, but some portions were observed to be dissipating at the time of seeding. All observations revealed that the dissipation observed was more rapid when the clouds were seeded with dry ice than when they were seeded with water.

The airplane beacons were too sporadic to efficiently coordinate the mission by radar control, but cloud conditions were such that the observers in the various aircraft could keep in visual contact with each other on all seeding runs except the first two. In any event, there were very few cloud echoes on the radar scope, and the ones that were present were easily differentiated from the seeded areas through visual observations of the scope at the time of the mission. Following the second seeding, the observers in the seeding aircraft were able to observe the base of the cloud, and they reported that no rain fell from it. There was a small cloud echo on the scope about 8 miles south of the second seeding area and about 40 to 45 miles southwest of the third and fourth seeded areas.

Even though complete coordination was not attained, no echoes from the seeded areas formed

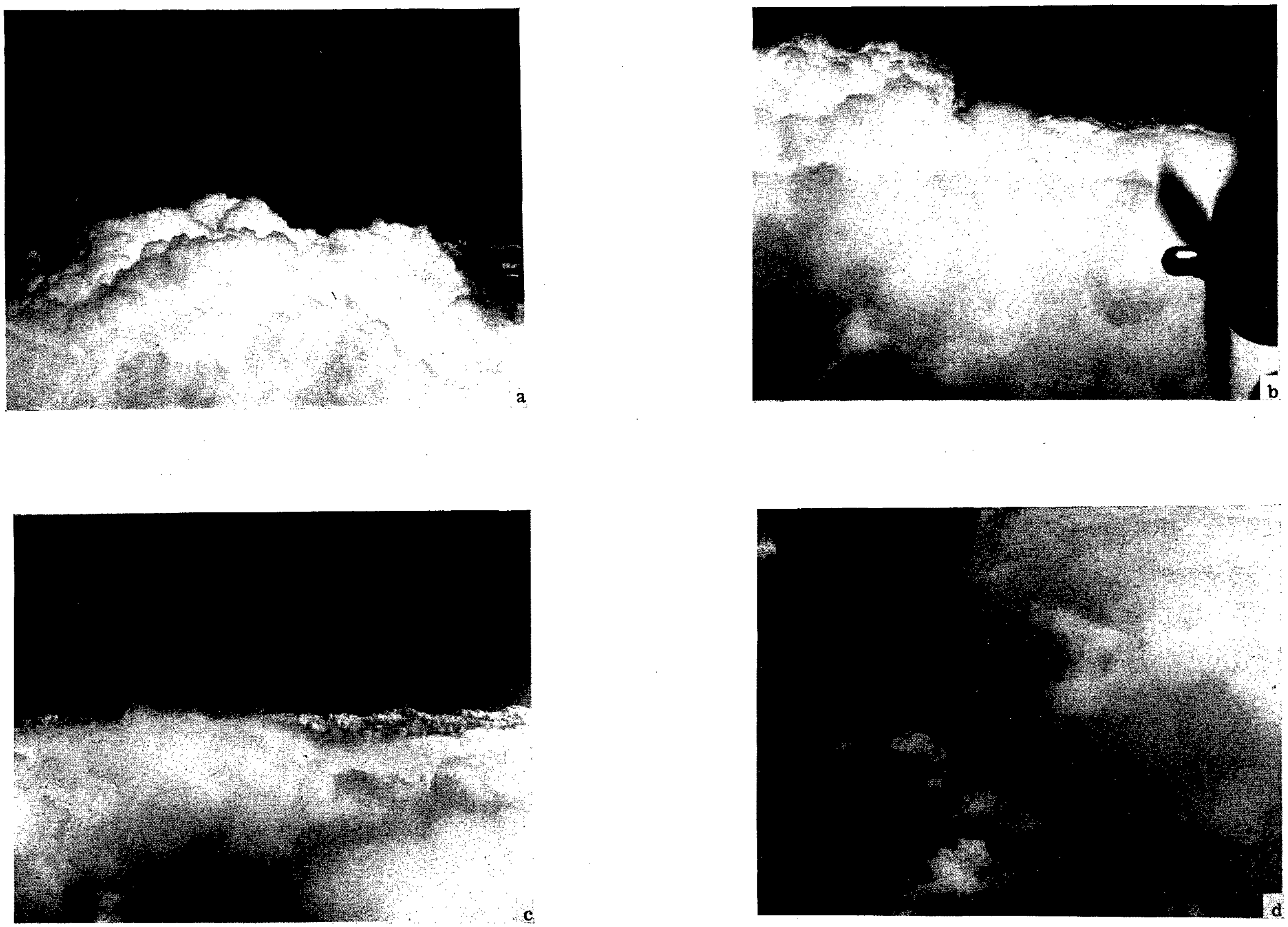


FIGURE 26.—Sequence of cloud pictures from second seeding run on August 17, 1948. (a) 1402 E. S. T. View of cloud to be seeded. (b) 1411 E. S. T. View of cloud about 6 minutes after seeding, showing change in density as compared with the unseeded cloud in the background. (c) 1417 E. S. T. View of cloud about 12 minutes after seeding, showing wispy top. (d) 1431 E. S. T. Later view of base of cloud, showing faint rainbow in center of picture.

on the radar scope; therefore, it can be safely concluded that if any rain did fall after seeding, it must have been very light and inconsequential economically.

CLOUD SEEDING OF AUGUST 17, 1948

Synoptic situation.—The area of seeding operations was in a very weak pressure field at 1330 E. S. T. A variable amount of altocumulus and swelling cumulus clouds covered southwestern Ohio. The only frontal system was located a considerable distance northwest of the seeding areas, and the indications were that the front would have no effect on the seeding operations.

Conditions of seeding.—Attempts were made to seed four cumulus clouds. On the third run, the cloud top dissipated before it could be seeded; therefore, it is omitted from this report. The tops of the cumuli were at 15,300 feet mean sea level, 15,000 feet, and 16,000 feet, respectively, with temperatures near the tops ranging from $-5.0°$ to $-6.0°$ C. The bases on the first two runs were near 6,000 feet, and on the fourth run, near 6,300 feet, with temperatures ranging from $+12.0°$ to $+11.0°$ C. The freezing level was near 11,800 feet mean sea level.

Rate of seeding.—Twenty pounds of granulated dry ice were dropped instantaneously on the first two runs and 40 pounds on the fourth run. In addition, dry ice pellets were dropped at the rate of 6 pounds per mile on each run.

Time and duration of seeding:

1st seeding: 1333:40 E. S. T.; 1 minute.
2d seeding: 1404:45 E. S. T.; 40 seconds.
3d seeding: Not included.
4th seeding: 1449:35 E. S. T.; 40 seconds.

Results.—The first cloud grew vertically about 800 feet after seeding and then dissipation set in. The final result observed was that the top of the cloud dropped below 15,000 feet mean sea level, when the original top had been near 15,300 feet. The second cloud also grew vertically for a short time after seeding and then dissipated at the top (fig. 26 (a), (b), (c)). The total amount of dissipation of both clouds was estimated at about 50 percent. The third cloud (fourth run) began to dissipate after seeding and finally took on a stratiform appearance.

Very light rain was observed to have fallen from the clouds after the second and fourth runs, but the rain was not believed to have reached the ground. No precipitation was observed after the first seeding.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual) and photographs of seeded cloud.
   b. 2d seeding: Aerial observations (visual) and photographs of seeded cloud (fig. 26).
   c. 3d seeding: Not included.
   d. 4th seeding: Aerial observations (visual).
      (Note: Pictures taken of 4th seeding, but they did not show the results observed visually.)
2. Precipitation:
   a. 1st seeding: Aerial observations (visual) and visual observations of CPS–6 radar scope at time of mission.
   b. 2d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.
   c. 3d seeding: Not included.
   d. 4th seeding: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—All clouds which were seeded were observed to dissipate partially after seeding, although they were building at the time of seeding. The observers were unable to tell how much, if any, texture change was accomplished by the first seeding; but since the cloud was supercooled, it is believed that some took place.

The precipitation observed after the second and fourth seedings was very light. A cloud echo formed on the radar scope in the second seeded area about 14 minutes after seeding, and the observers in the seeding aircraft reported a rainbow below the cloud (fig. 26 (d)). The echo disappeared within approximately 12 minutes, and the area in which the echo was present did not pass over a rain gage. Precipitation after the fourth seeding (observed 19 minutes after seeding) was not heavy enough to produce an echo on the radar scope. In fact, the observers in the low observation plane reported that they encountered only a few drops of rain. There were no natural showers within 30 miles of the seeded area.

CLOUD SEEDING OF AUGUST 18, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was immediately ahead of a weak cold front. The front was close enough to influence the cloud development in the area of seeding operations. Stratocumuli and swelling cumuli were prevalent ahead of the front, with fair-weather type cumuli northwest of the front. A few showers had occurred ahead of the front in the 6-hour period preceding 1330 E. S. T.

Conditions of seeding.—Cumulus clouds were seeded five times. The tops of the clouds were at 16,000 feet mean sea level, 15,000 feet, 17,000 feet, 14,500 feet, and 14,000 feet, respectively, with temperatures in the vicinities of the tops of $-6.0°$, $-5.0°$, $-8.0°$, $-4.0°$, and $-3.0°$ C., respectively. Bases of the clouds ranged from 4,500 feet mean sea level to 5,000 feet, with temperatures in their vicinities varying from $+13.0°$ to $+15.0°$ C. A broken stratocumulus cloud deck was also present, based at 4,500 feet. On the fourth run, two clouds were flown through consecutively but only the second was seeded. The freezing level was near 12,200 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 4, 5, 4, and 7 pounds per mile, respectively, on the first four seeding runs. In

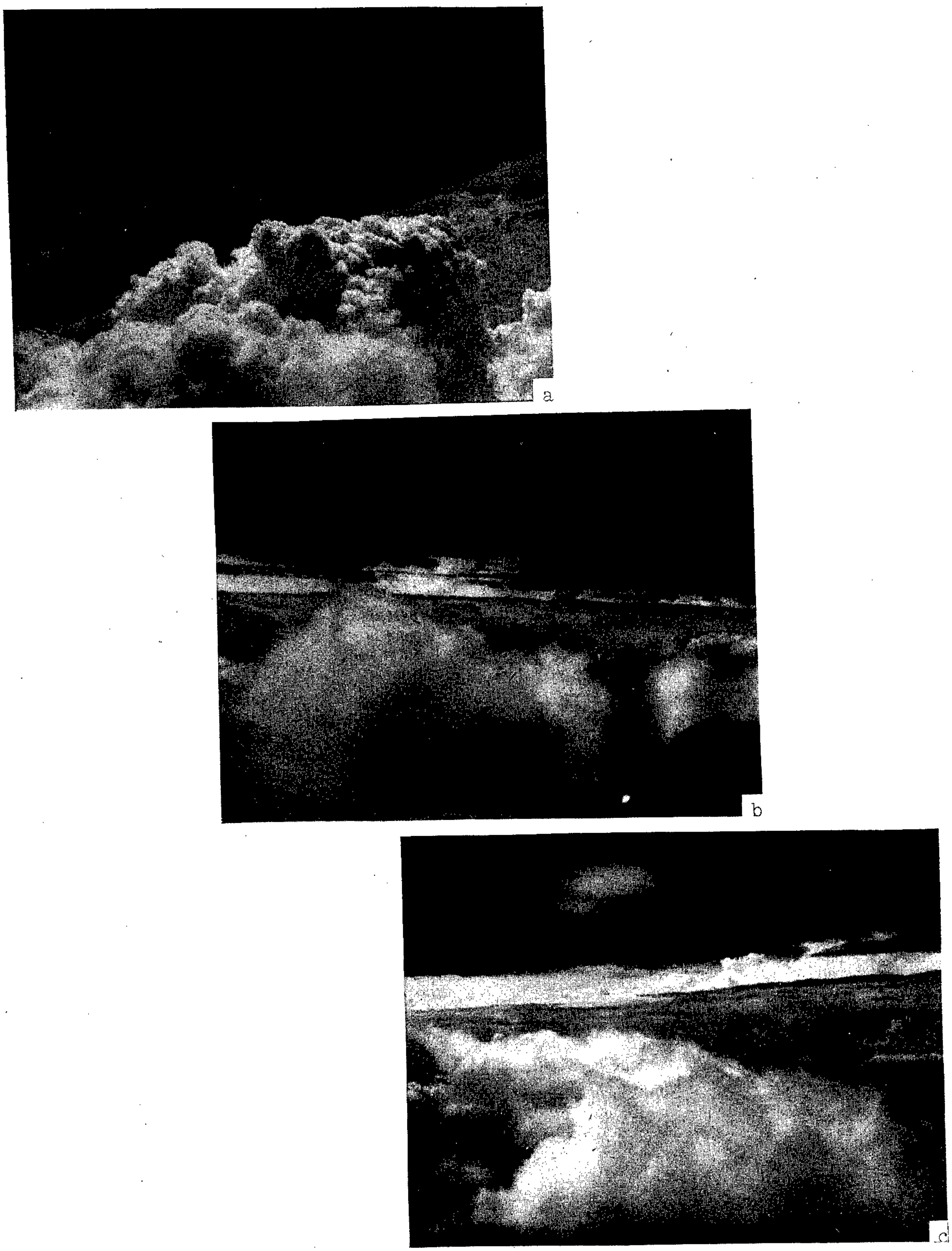


FIGURE 27.—Sequence of cloud pictures from first seeding run on August 30, 1948. (a) 1400 E. S. T. View of cloud to be seeded. (b) 1416 E. S. T. View after seeding showing some dissipation. (c) 1420 E. S. T. Later view of seeded cloud showing how the body of the cloud decreased in size.

addition, 20 pounds of granulated dry ice were dropped instantaneously on the 2d and 3d runs. Vaporized lead oxide was used as the nucleating agent on the fifth run.

Time and duration of seeding:

1st seeding: 1302:15 E. S. T.; 50 seconds.
2d seeding: 1336:45 E. S. T.; 15 seconds.
3d seeding: 1403:20 E. S. T.; 55 seconds.
4th seeding: 1422:15 E. S. T.; 40 seconds.
5th seeding: 1513:50 E. S. T.; duration unknown.

Results.—After the first seeding, the cloud built slightly and then changed texture, with about 20 percent dissipation. It lost its cumuliform appearance and became stratified. Following the second seeding, the cloud built up about 1,500 feet and then dissipated very rapidly, with only fragments remaining. The third seeding resulted in about 75 percent of the cloud dissipating. Following the fourth run, both clouds (the one flown through and the seeded cloud) were observed to dissipate partially, but the seeded cloud dissipated in greater amount and at a faster rate than the unseeded one. The fifth seeding also resulted in partial dissipation, with the seeding path visible in the cloud and the top dropping down. No precipitation was observed to fall from any of the seeded clouds either before or after seeding.

Method of verification:

1. Structural:

   All seedings: Aerial observations (visual) and photographs of seeded cloud.

   (Note: Pictures of 2d seeding did not show complete results that were observed visually.)

2. Precipitation:

   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Dissipation was observed in the first two clouds although they were building at the time of seeding. The last three seedings were into clouds that were dissipating at the time of seeding. In fact, natural dissipation was so active on the third seeding run that the seeded cloud was hard to locate soon after seeding. The top of the third cloud dropped considerably on the seeding run.

Natural precipitation areas were present within 30 miles of all seeded areas; yet no cloud echoes appeared on the radar scope in the seeded areas. At one time the observers in the low observation plane reported light rain, but the plane was about 4 miles north of the fifth seeded cloud and within 3 miles of a natural echo on the radar scope; therefore, the rain observed was probably falling from the cloud that was producing the echo on the radar scope. The observers in the low aircraft verified that the rain was not falling from the seeded cloud.

CLOUD SEEDING OF AUGUST 30, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was immediately behind a cold front oriented approximately east-west through southern Ohio. Skies were generally cloudy over southwestern Ohio, with stratocumulus, cumulus, and cumulonimbus clouds. A thundershower was occurring at Columbus, Ohio, at map time. A squall line approximately 130 miles long was 50 miles northwest of the seeding area. The squall line moved into the second seeded area by 1515 E. S. T.

Conditions of seeding.—Two seeding runs on cumulus clouds were made. The tops of the clouds were near 16,700 feet mean sea level, with temperatures in the vicinities of −5.0° C. Bases of the clouds were at 7,200 feet and 5,500 feet, respectively, with temperatures ranging from +14.0° to +17.0° C. Broken stratocumulus clouds and some altocumulus clouds were also present. The freezing level was near 13,800 feet mean sea level.

Rate of seeding.—Water was sprayed into the clouds on all seeding runs.

Time and duration of seeding:

1st seeding: 1400:20 E. S. T.; 50 seconds.
2d seeding: 1439:20 E. S. T.; 1 minute.

Results.—About 75 percent of the first cloud dissipated after seeding (fig. 27). There were two bulges on the cloud and only one was seeded. Although both bulges dissipated, the seeded one dissipated more rapidly. Following the second seeding, the cloud built up considerably, with a thunderstorm forming, but it is doubtful that it resulted from the seeding.

No precipitation was observed after the first seeding. Rain was observed after the second seeding, but it is doubtful that it resulted from the seeding.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual) and pictures of seeded cloud (fig. 27).
   b. 2d seeding: Aerial observations (visual).
2. Precipitation:

   Both seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Dissipation was observed in the first cloud although it was building slightly at the time of seeding. It was significant that both bulges dissipated when only one bulge was seeded. The seeded bulge, however, dissipated more rapidly.

Although light rain was reported in the first seeded area, the coordination of the plane positions on the radar scope with the location of the rain area reported indicated that the rain was coming from an area about 6 miles northeast of the seeded cloud. The echo was faint and did not show up on the pictures of the scope, but its position was observed visually on the scope at the time of the mission.

The precipitation observed after the second seeding was probably not the result of seeding. Since the cloud was building and continued to build after seeding, it is doubtful that the seeding had any effect. The rate of development did not seem to be accelerated after seeding. In fact, a natural echo formed about 4 miles north of the seeded cloud about 2 minutes before the echo which appeared in the seeded area, and another natural echo formed south of the seeded area at about the time the second cloud was seeded. Numerous other cloud echoes were forming and dissipating both before and after seeding very close to the seeded cloud. Indications were that the bases of the clouds seeded coincided with the height of the frontal surface over the seeded area. Since the air was convectively unstable, the formation of the showers must have been the result of frontal activity; therefore, it is logical to assume that the rain observed after the second seeding would have occurred without seeding. The seeded area did not pass over a rain gage, but cloud echoes very close by produced as much as 0.27 inch of rain within 4 hours.

CLOUD SEEDING OF SEPTEMBER 7, 1948

Synoptic situation.—The area of seeding operations at 1330 E. S. T. was located in a very weak pressure field. A weak cold front was located in a north-south line through central Indiana, but pressure tendencies around the front indicated that it probably would not progress eastward far enough to affect the seeded areas. Cumulus and stratocumulus clouds were prevalent over southwestern Ohio and a few showers had occurred in the 6-hour period preceding 1330 E. S. T.

Conditions of seeding.—Cumulus clouds were seeded four times. On the first run, the aircraft was flown through the cloud 600 to 700 feet below the top of the cloud without the dropping of any nucleating material. The tops of the clouds were 19,200 feet mean sea level, 17,300 feet, 17,500 feet, and 16,000 feet, respectively, with temperatures near the tops ranging from −8.0° to −4.0° C. Bases of the clouds were variable, between 2,700 feet and 4,100 feet, with temperatures ranging from +17.0° to +21.0° C. Light to moderate turbulence was encountered in all clouds that were flown through. The freezing level was at 14,100 feet mean sea level.

Rate of seeding.—The aircraft was flown through the first cloud without dropping any seeding material. Dry ice was dropped on the other runs at the rate of 4 pounds per mile.

Time and duration of seeding:

1st seeding: 1418:15 E. S. T.; 10 seconds.
2d seeding: 1431:45 E. S. T.; 10 seconds.
3d seeding: 1449:10 E. S. T.; 20 seconds.
4th seeding: 1517:25 E. S. T.; 10 seconds.

Results.—After the flight through the first cloud, the top built about 1,000 feet and then dissipated. Following the second seeding, the top changed texture and the top portion of the cloud dissipated. After the third seeding, the seeded portion of the cloud showed dissipation. The north side dissipated within 15 minutes. Within 5 minutes after the fourth seeding a hole formed through the cloud (fig. 28 (d)).

Precipitation was observed below the first three clouds, but they were already producing rain and appearing as echoes on the radar scope prior to the seeding runs. A rainbow was observed below the third cloud. The fourth cloud did not form an echo on the radar scope, and no rainfall was observed below the base of the cloud.

Method of verification:

1. Structural:
   a. 1st three seedings: Aerial observations (visual).
   b. 4th seeding: Aerial observations (visual) and pictures of seeded cloud (fig. 28).
2. Precipitation:
   All seedings: Aerial observations (visual) and pictures of CPS–6 radar scope.

Comments.—Three clouds in which dissipation was observed were building at the time of seeding. The second cloud was in the dissipation stage at the time it was seeded.

A cloud echo was present on the radar scope prior to the first three seeding runs. The echo that was present at the time of the first seeding continued to grow after seeding, with its final size being about twice the size at the time of seeding. Since the echo was growing and continued to grow after seeding, it is doubtful that the seeding had any effect on it. Echoes from the second and third clouds disappeared from the scope, however, after the seeding with dry ice, the second about 16 minutes later, the third about 14 minutes later. Another echo about 10 miles southwest of the second cloud disappeared through natural causes at the same time the echo from the seeded cloud was disappearing. Other echoes from areas very close to both the second and third seeded areas, however, were forming, or those already present were increasing in size at the time that the echoes from the seeded clouds disappeared. No rainfall was observed in the fourth seeded area, but natural showers were occurring about 25 to 28 miles to the southwest.

CLOUD SEEDING OF SEPTEMBER 8, 1948

Synoptic situation.—At 1330 E. S. T., a weak low pressure system was centered in central Illinois, with the warm front oriented east-west across northern Indiana and Ohio. Cirrus clouds with lower towering cumuli were the predominant ones over southwestern Ohio. The pressure gradient was weak over the area of seeding operations.

Conditions of seeding.—Cumulus clouds were seeded three times. The tops ranged from 16,800 feet mean sea level to 19,200 feet, with temperatures in the vicinities of the tops of −2.0°, −3.0°,

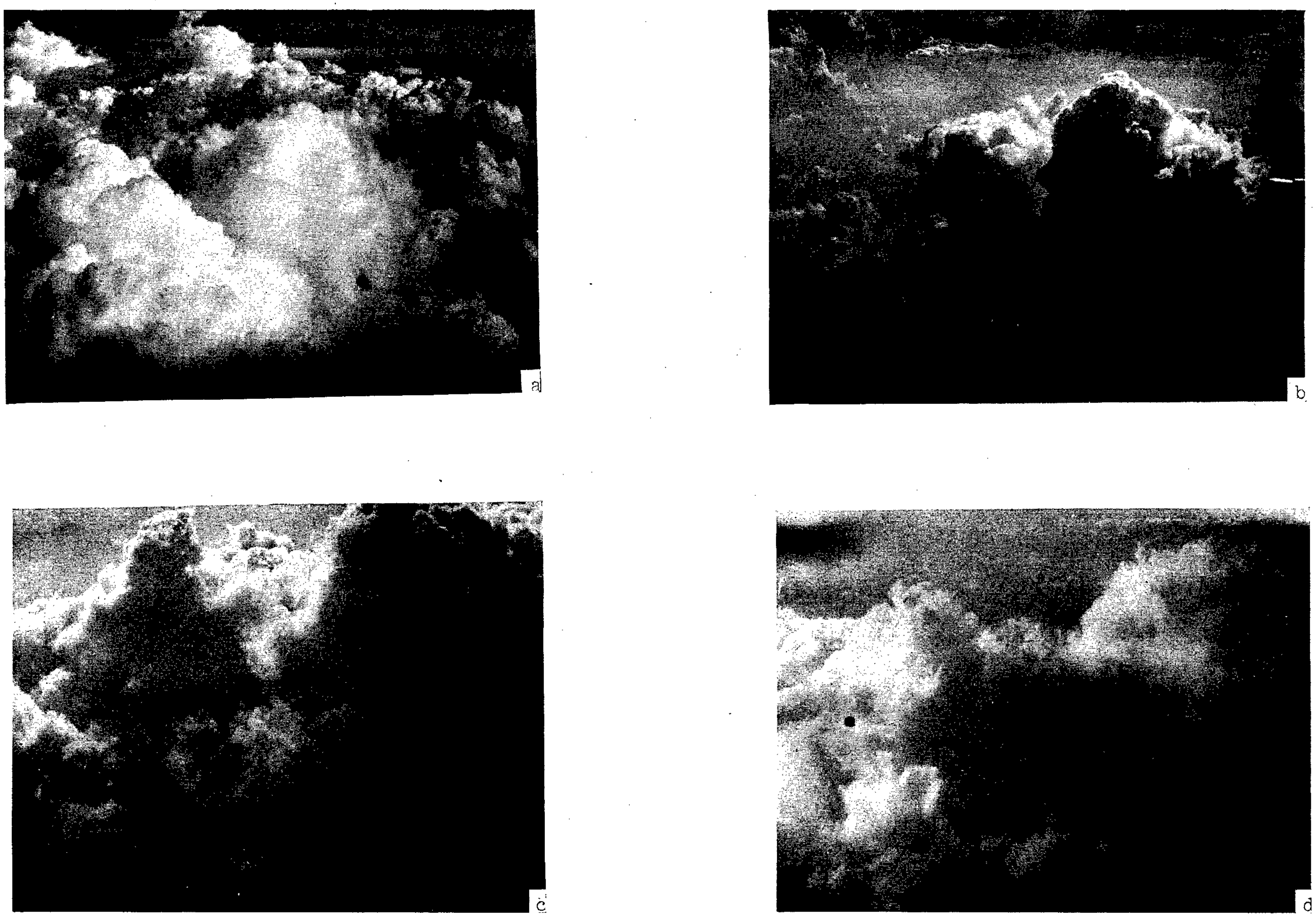


FIGURE 28.—Sequence of cloud pictures from fourth seeding run of September 7, 1948. (a) 1520 E. S. T. View of cloud immediately after seeding. (b) 1526 E. S. T. (c) 1533 E. S. T. (d) 1535 E. S. T. View of cloud showing hole in center that formed as a result of the seeding.

and $-6.0°$ C., respectively, on the seeding runs. A significant shear in the wind velocity was present near 10,000 feet mean sea level, and a large number of the cumulus tops were being sheared off at that level. Observations revealed that the top portions of the clouds, when extending into the area of increased wind velocity, were carried ahead of the main bodies of the clouds and eventually dissipated. Some of the clouds, however, were able to build above the wind shear level, but all of them leaned conspicuously to the southeast. All clouds that were seeded were of this type. The freezing level was at approximately 14,000 feet mean sea level.

Rate of seeding.—Dry ice pellets were dropped at the rate of 5 pounds per mile on the first run. Water was sprayed into the cloud on the second run, and the airplane was flown through the cloud without the dropping of any nucleating material on the third run.

Time and duration of seeding:

1st seeding: 1428:10 E. S. T.; 40 seconds.
2d seeding: 1443:44 E. S. T.; 16 seconds.
3d seeding: 1504:43 E. S. T.; 22 seconds.

Results.—Following all three seeding runs, the clouds tended to dissipate. The first two clouds dissipated about 75 percent, and the third cloud about 50 percent. The high photo plane also flew through a cloud top and an appreciable amount of dissipation was observed in it also.

No precipitation was observed to fall from any of the seeded clouds.

Method of verification:

1. Structural:
   a. 1st seeding: Aerial observations (visual).
   b. 2d seeding: Aerial observations (visual) and pictures of seeded cloud.
   c. 3d seeding: Aerial observations (visual) plus observations by surface observer. (Note: Pictures did not show complete results that were observed visually.)
2. Precipitation:
   a. 1st and 2d seedings: Aerial observations (visual) and pictures of CPS–6 radar scope plus visual observations of radar scope at time of mission.
   b. 3d seeding: Aerial observations (visual) and pictures of CPS–6 radar scope plus visual observations of radar scope at time of mission. Also, surface observations from Station No. 19 of surface network.

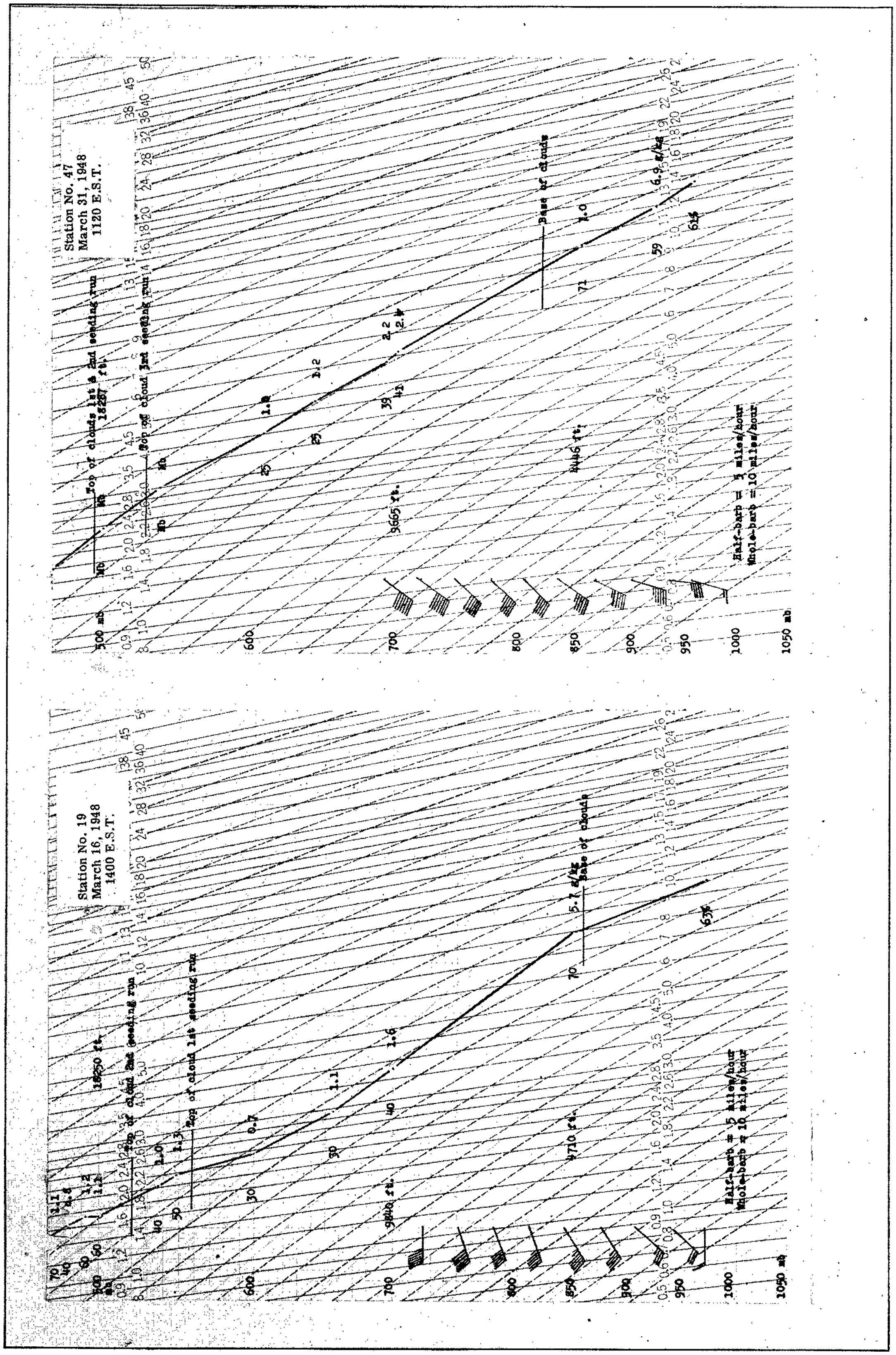
Comments.—All clouds that were seeded were observed to be building at the time of seeding, but since there was a wind shear present near 10,000 feet mean sea level, with some clouds dissipating above that level, the seeded clouds were probably having a struggle in maintaining themselves. The amount of dissipation observed regardless of the agent used may have been due to the fact that it required only a small amount of disturbance in the cloud top to upset the cloud and change it from a building cumulus to a dissipating one. The third cloud had three towers, all flown through by the aircraft. The surface observer at Station No. 19 of the surface network reported that he saw the plane fly through the cloud on the third run; a short time later, the cloud was observed to dissipate partially. The observer also reported that neighboring clouds were dissipating.

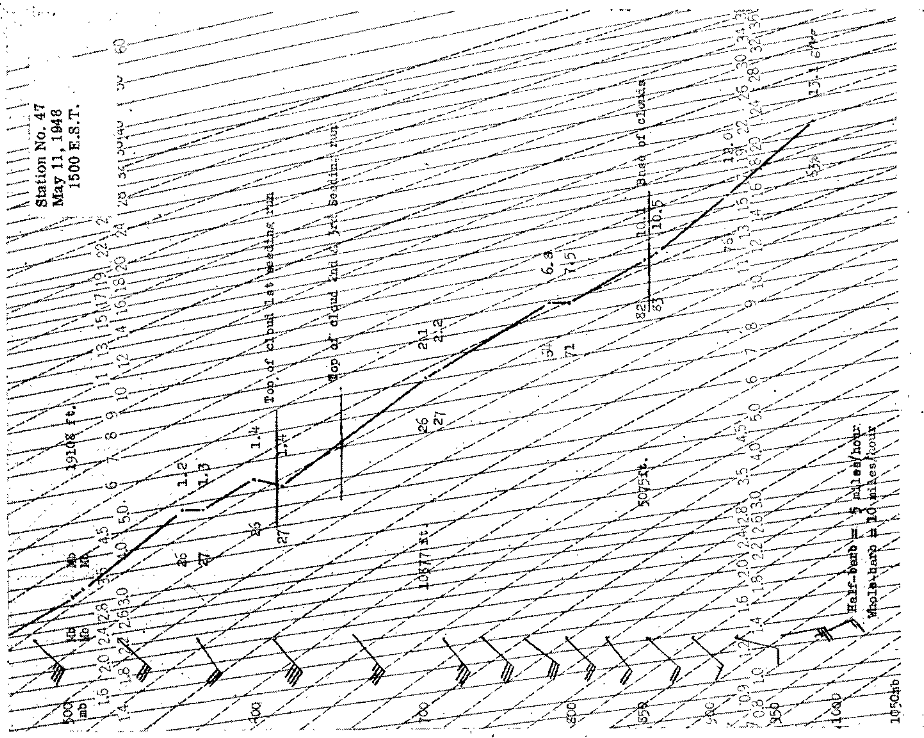
Although no precipitation was reported in the seeded areas, other very light showers were forming on the scope within 30 miles of the seeded areas. One, about 20 miles northeast of the second seeded area, started about 2 minutes prior to the second run. By the time of the third seeding, several showers were occurring within 6 miles of the seeded cloud. The first two clouds did not pass over a rain gage, but the third cloud passed over the rain gage network and the surface observer reported that no rain fell from it. Other showers were occurring over the southern edge of the network at the time of the third seeding, and the natural showers produced as much as 0.10 inch of rain.

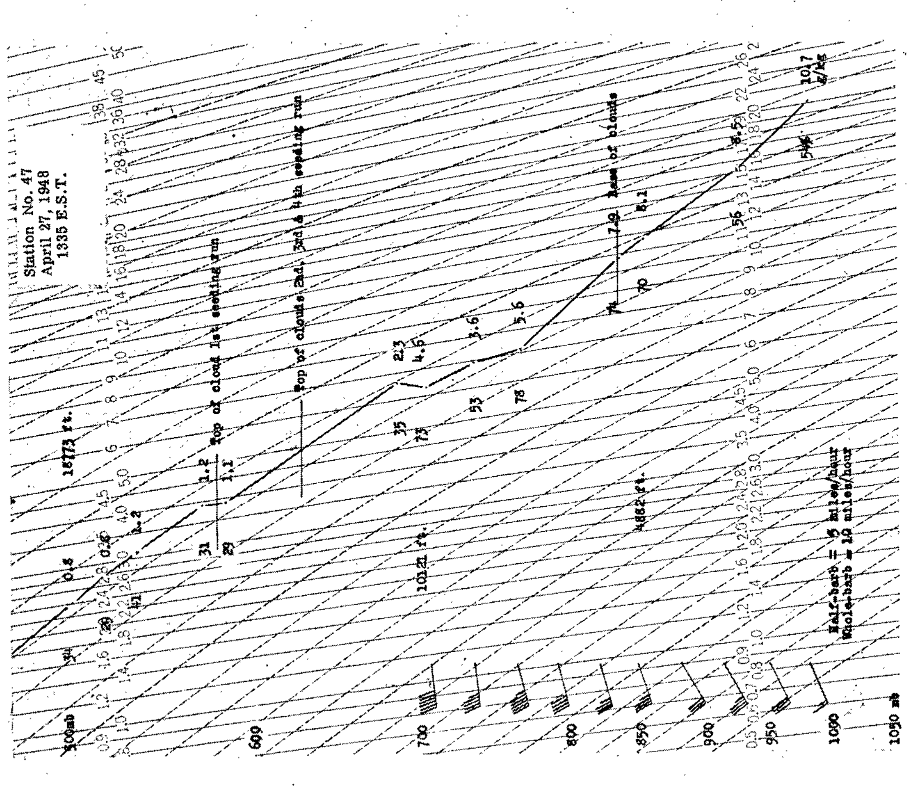
REFERENCES

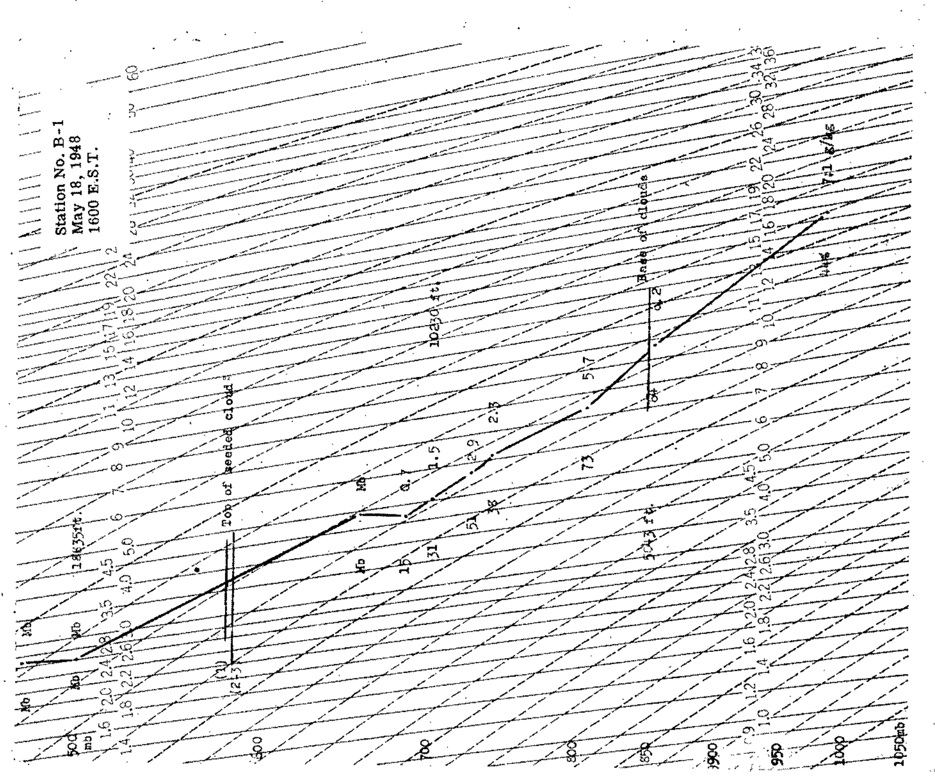
1. Henry Stommel, "Entrainment of Air into a Cumulus Cloud," *Journal of Meteorology*, vol. 4, No. 3, June 1947, pp. 91–94.
2. James M. Austin, "Note on Cumulus Growth in a Nonsaturated Environment," *Journal of Meteorology*, vol. 5, No. 3, June 1948, pp. 103–107.
3. H. R. Byers, and Roscoe R. Braham, Jr., "Thunderstorm Structure and Circulation," *Journal of Meteorology*, vol. 5, No. 3, June 1948, pp. 71–86.

ATMOSPHERIC SOUNDINGS

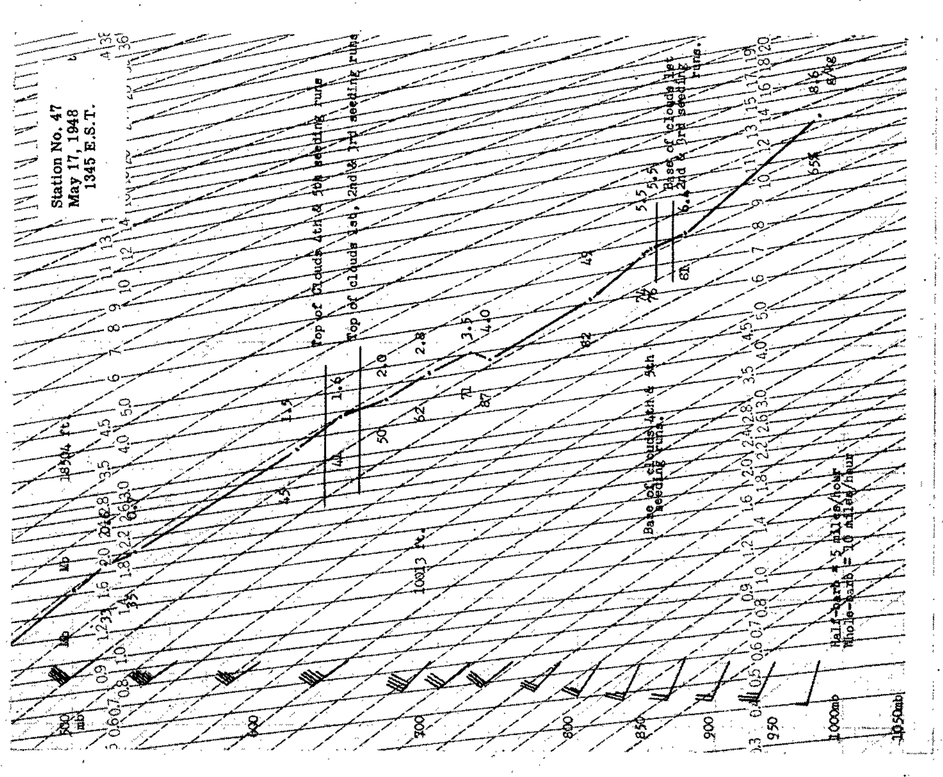



Station No. 47
May 11, 1948
1500 E.S.T.
Top of cloud 1st seeding run
Top of cloud 2nd & 3rd seeding run
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

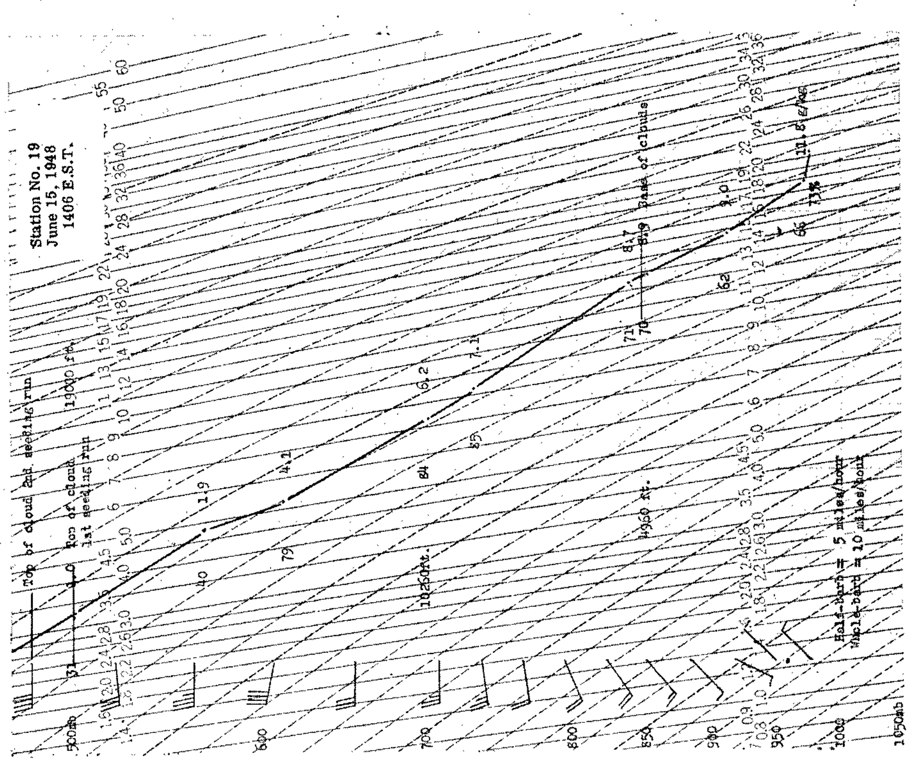

Station No. 47
April 27, 1948
1335 E.S.T.
Top of cloud 1st seeding run
Top of clouds 2nd, 3rd & 4th seeding run
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

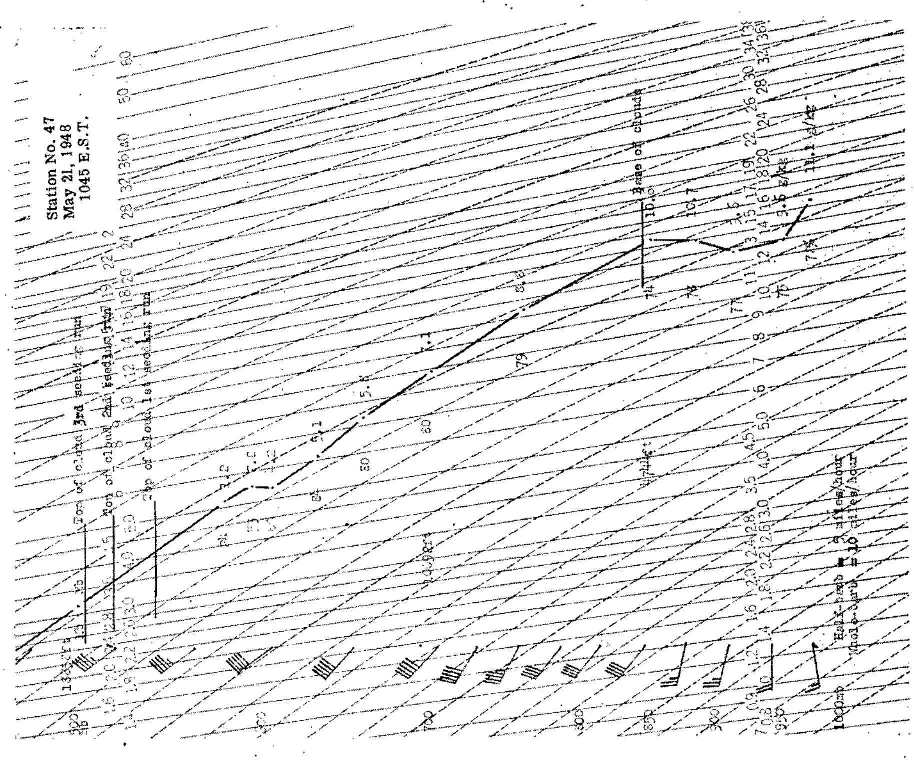


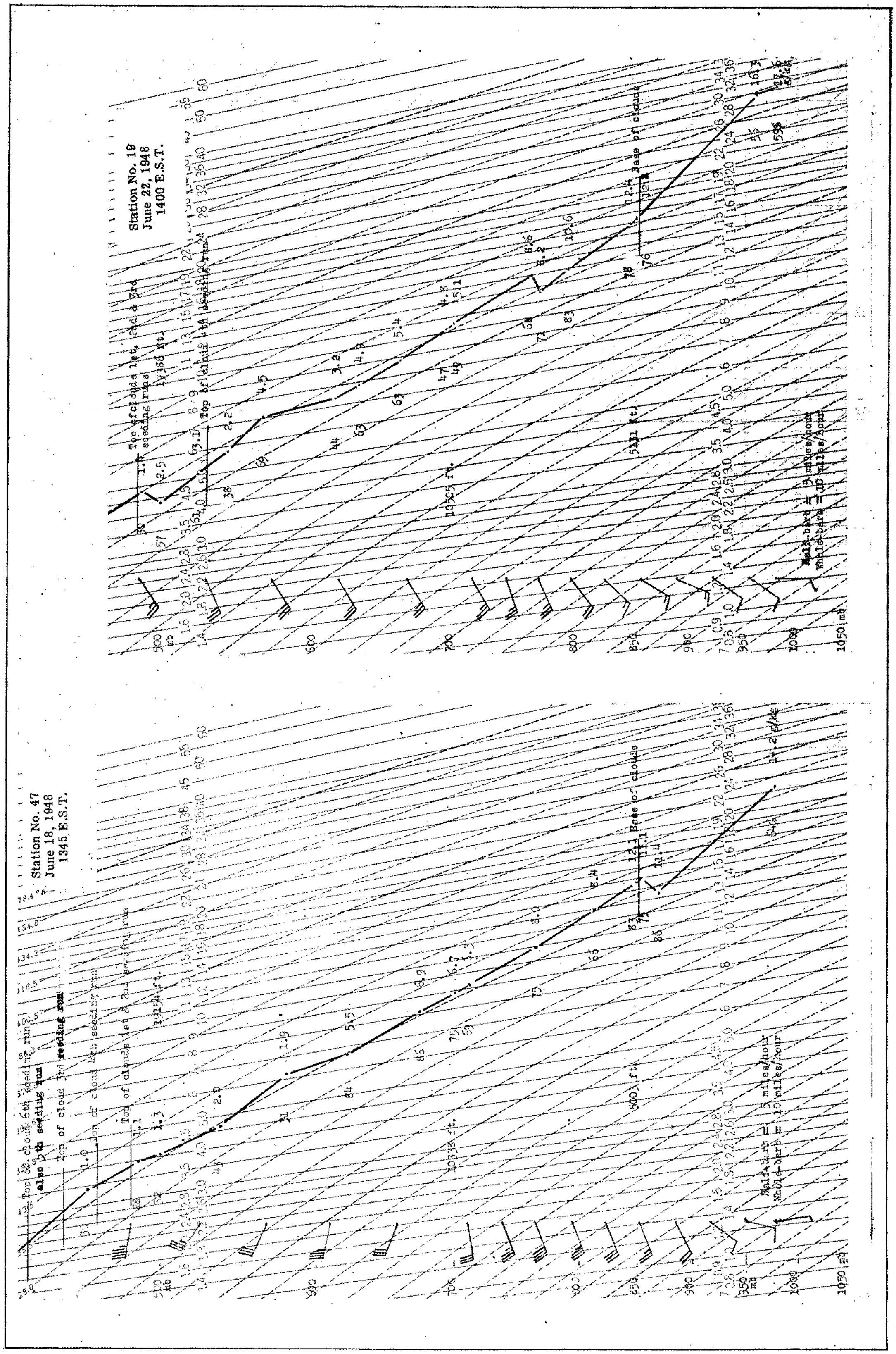
Station No. B-1
May 18, 1948
1600 E.S.T.
Top of seeded cloud
Base of clouds

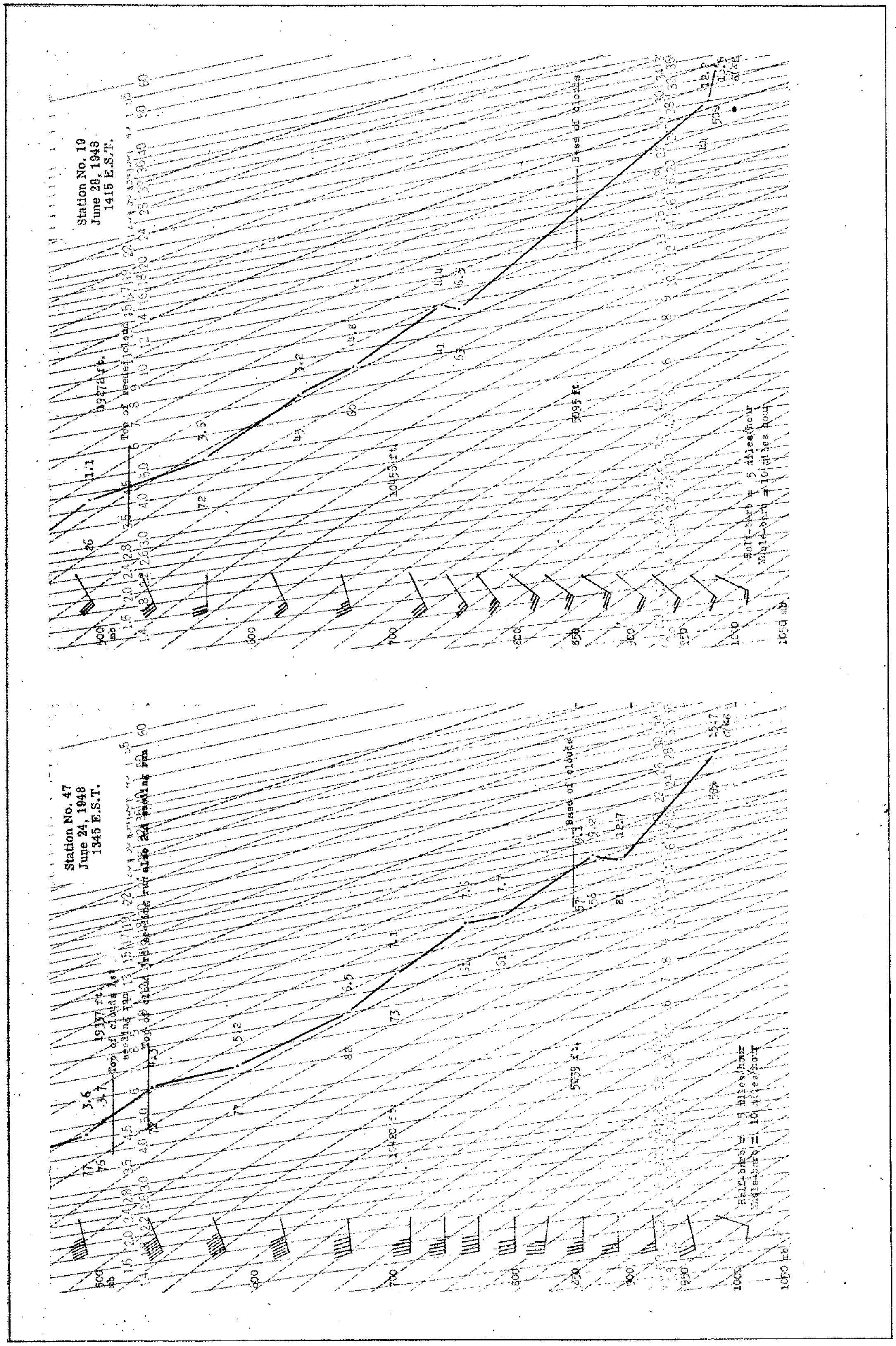


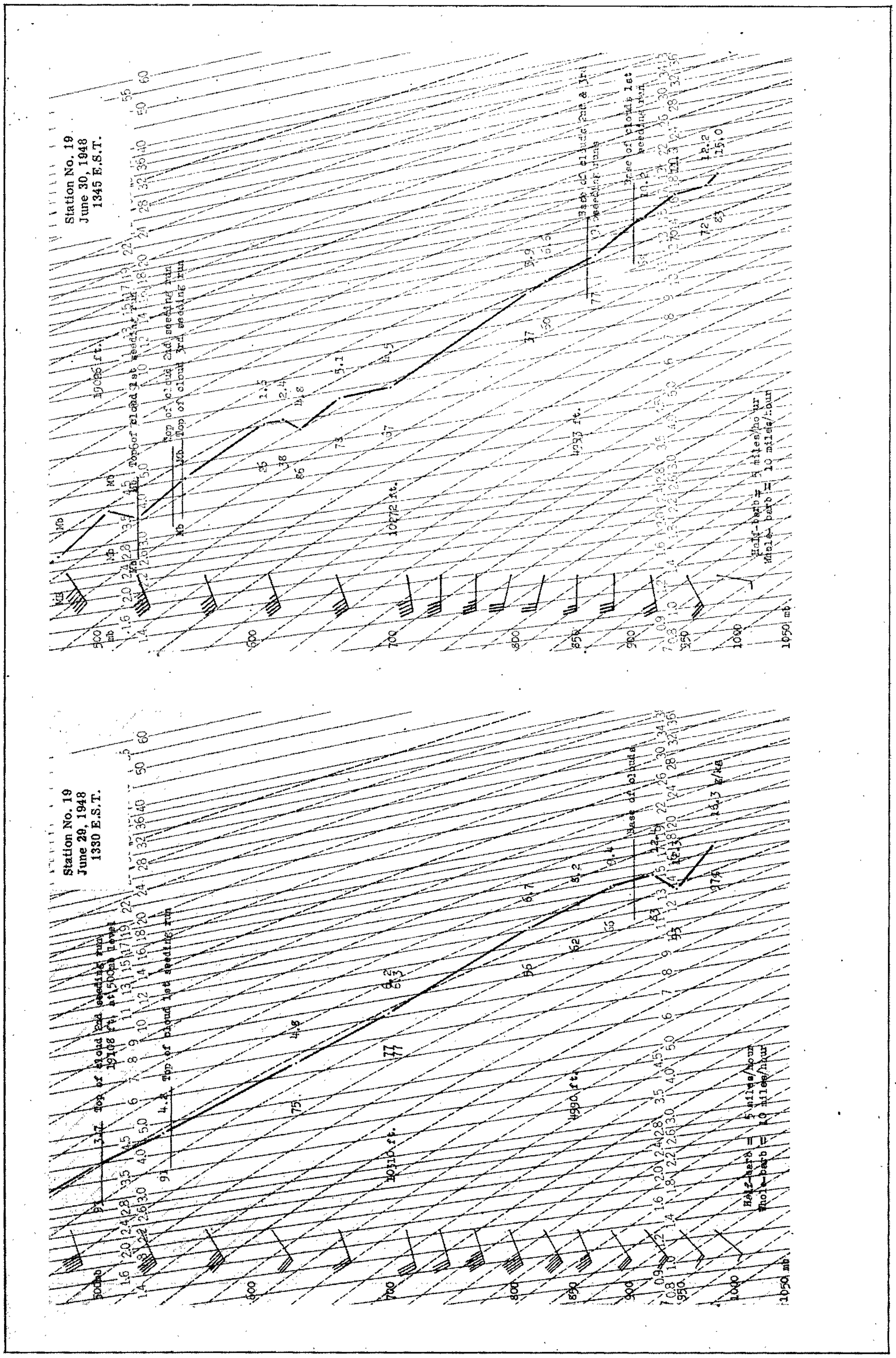
Station No. 47
May 17, 1948
1345 E.S.T.
Top of clouds 4th & 5th seeding runs
Top of clouds 1st, 2nd & 3rd seeding runs
Base of clouds 4th & 5th seeding runs.
Base of clouds 1st 2nd & 3rd seeding runs.
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

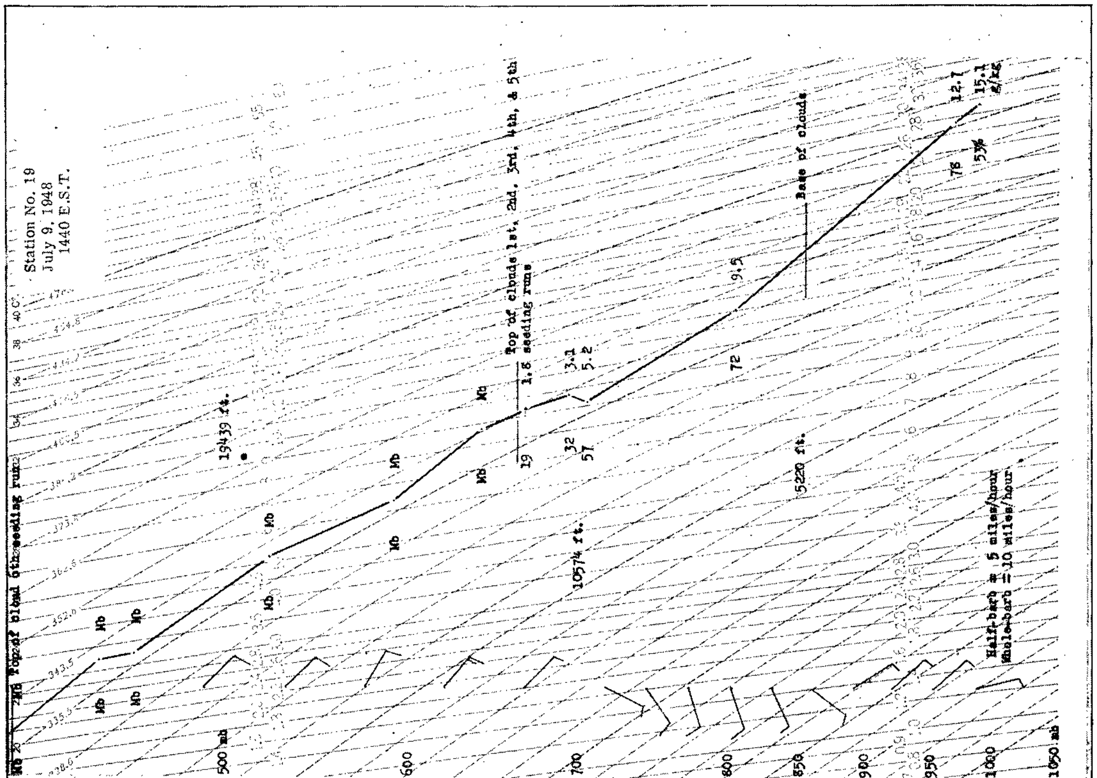

Station No. 19
June 15, 1948
1406 E.S.T.
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

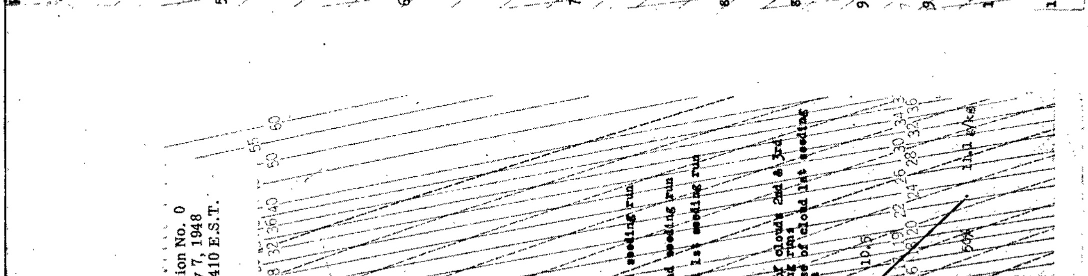

Station No. 47
May 21, 1948
1045 E.S.T.
Base of cloud
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

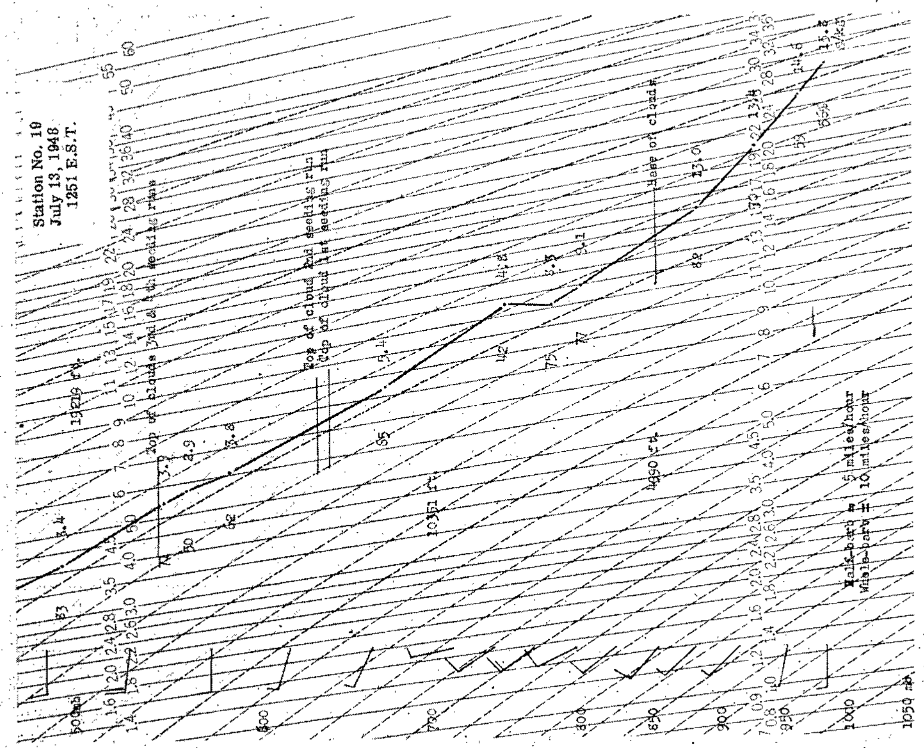

Station No. 19
June 22, 1948
1400 E.S.T.
Base of clouds
Station No. 47
June 18, 1948
1345 E.S.T.
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

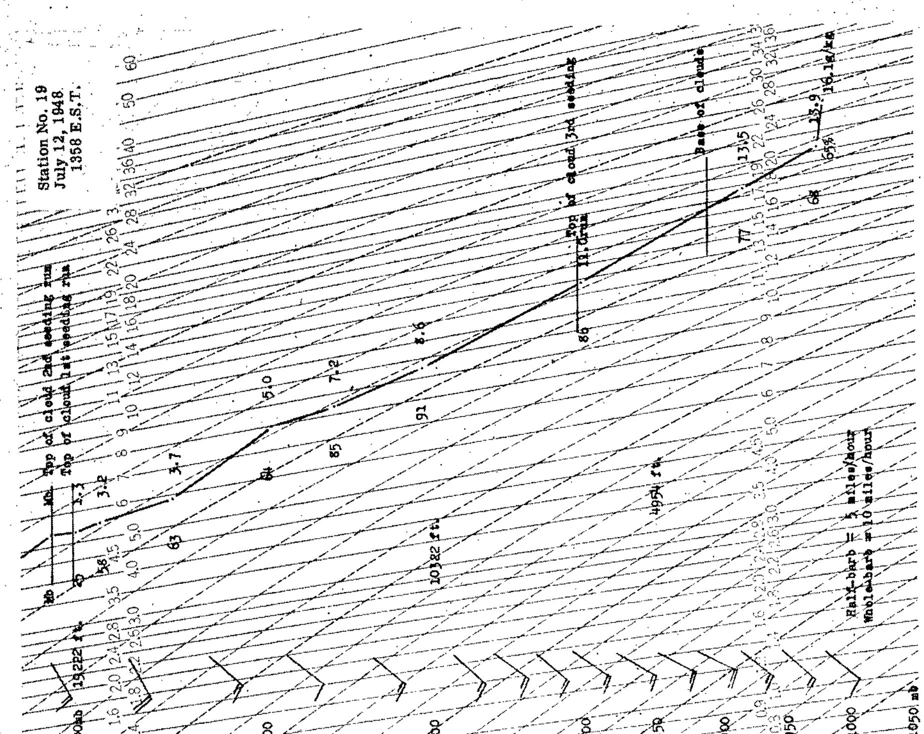

Station No. 19
June 28, 1948
1415 E.S.T.
Base of clouds
Top of seeded cloud
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
Station No. 47
June 24, 1948
1345 E.S.T.
Base of clouds
Top of clouds 1st seeding run
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

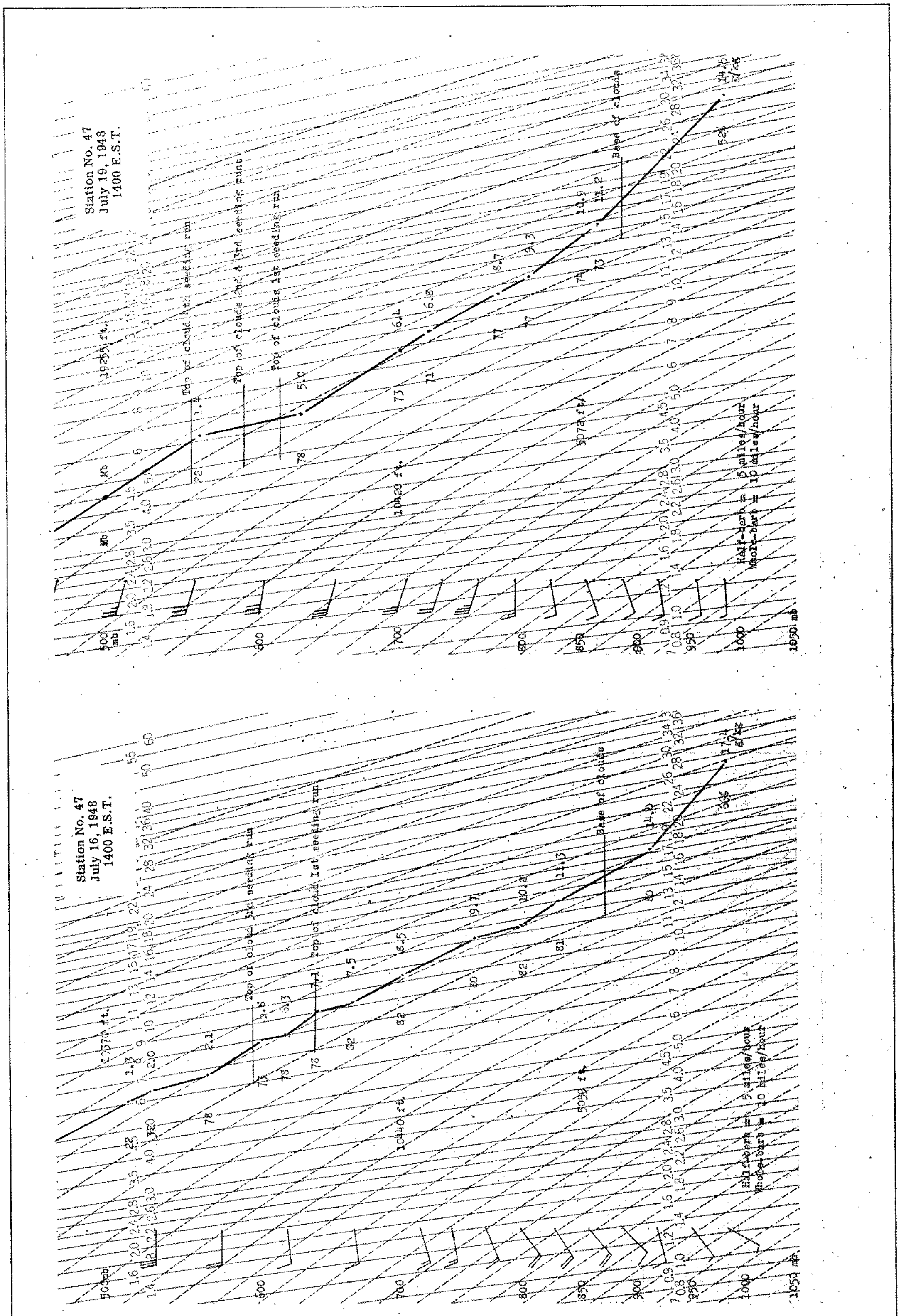

Station No. 19
June 29, 1948
1330 E.S.T.
Station No. 19
June 30, 1948
1345 E.S.T.
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

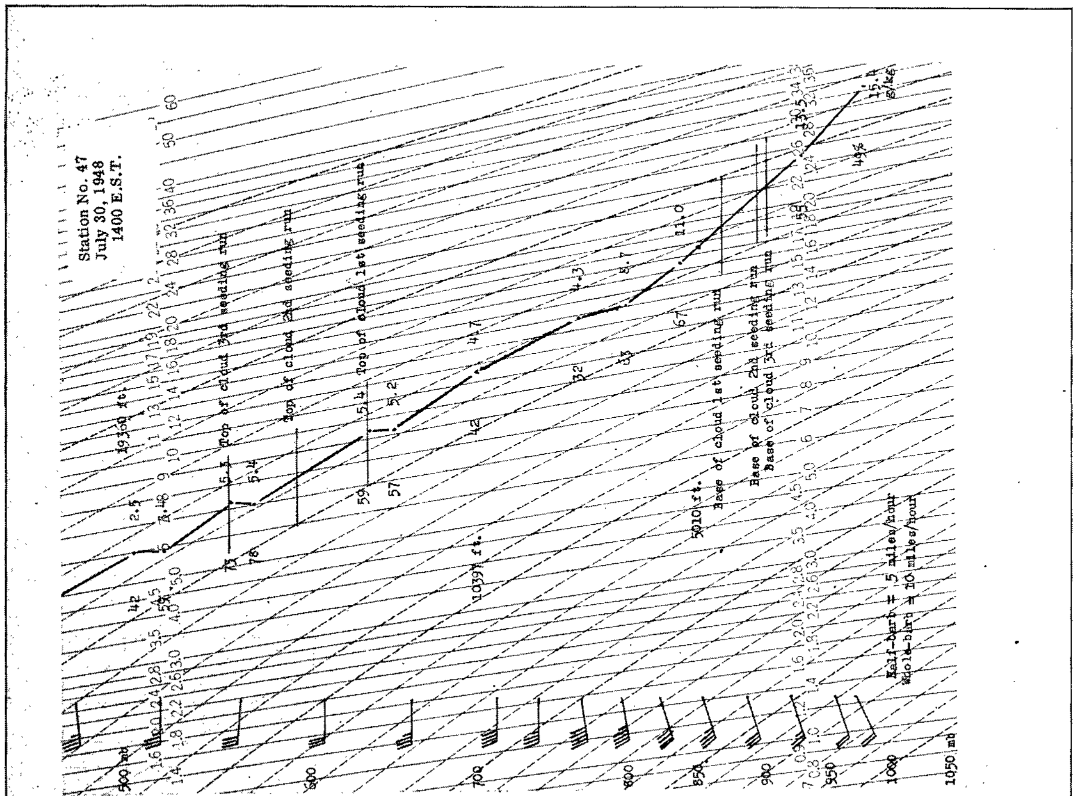

Station No. 19
July 9, 1948
1440 E.S.T.
Top of cloud 6th seeding run
19439 ft.
10574 ft.
5220 ft.
Top of clouds 1st, 2nd, 3rd, 4th, & 5th seeding runs
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
500 mb
600
700
800
850
900
950
1000
1050 mb

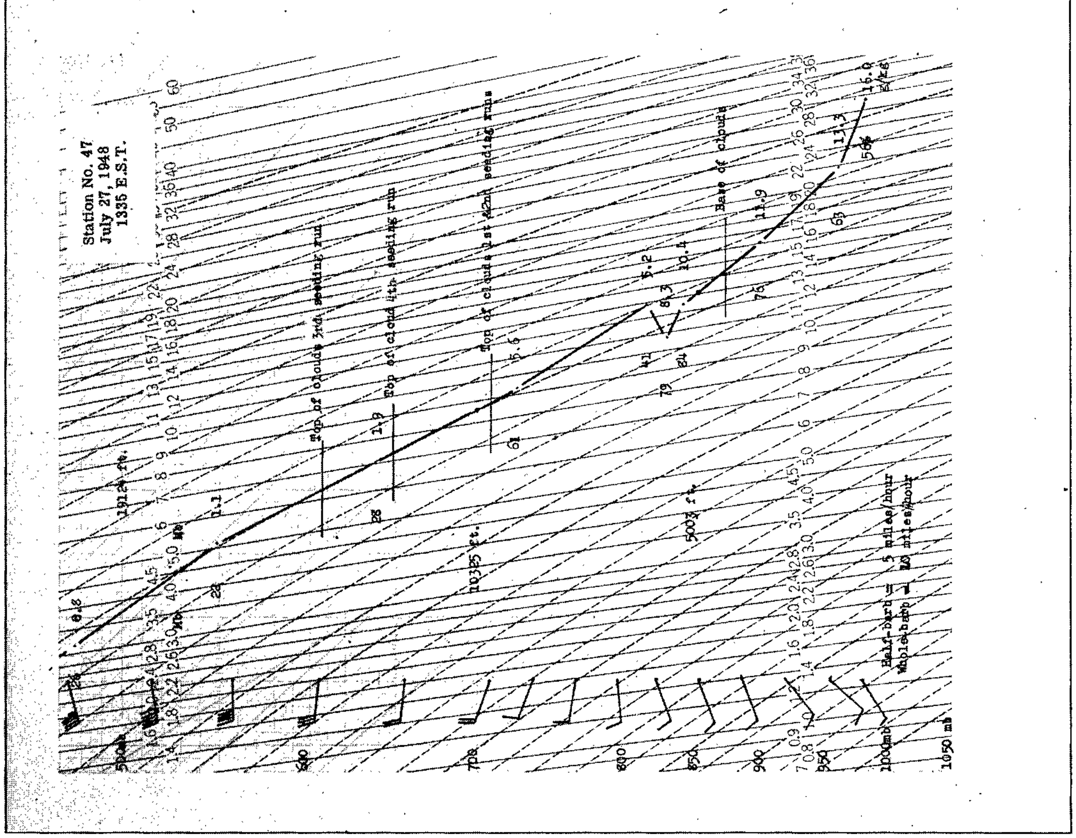

Station No. 0
July 7, 1948
1410 E.S.T.
Top of cloud 3rd seeding run
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Base of clouds 2nd & 3rd seeding runs
Base of cloud 1st seeding run
500mb
600
700
800
850
900
950
1000
1050 mb

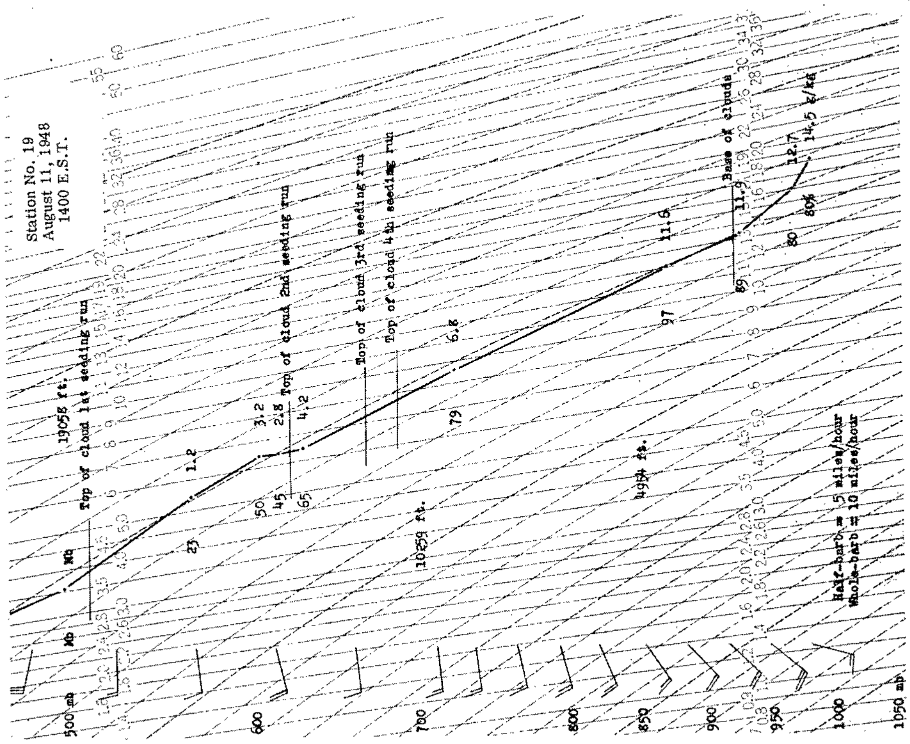

Station No. 19
July 13, 1948
1251 E.S.T.
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

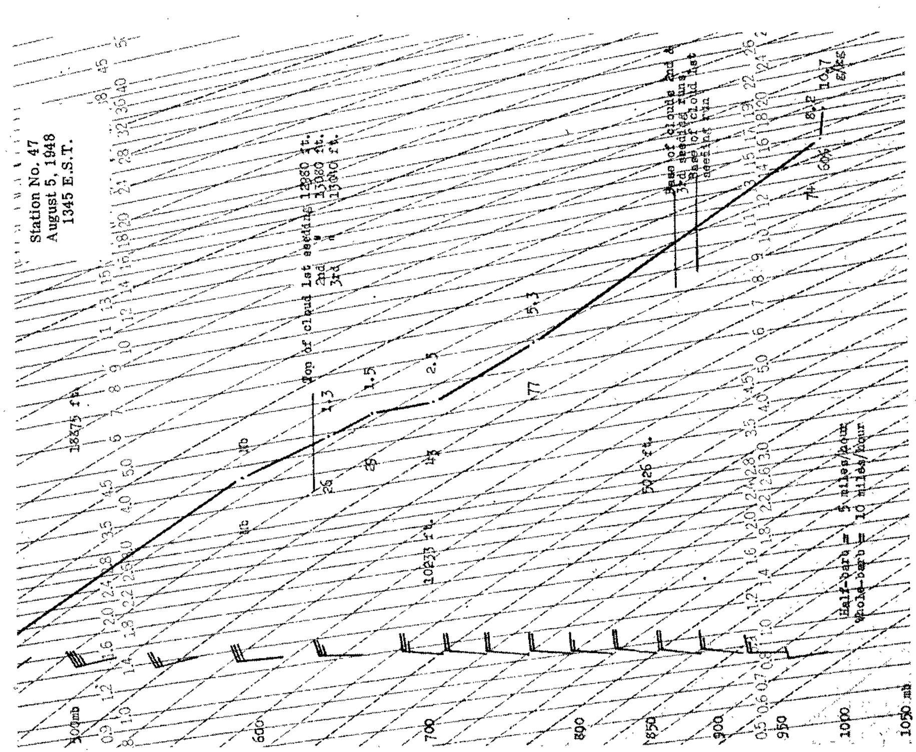

Station No. 19
July 12, 1948
1358 E.S.T.
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Top of cloud 3rd seeding
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

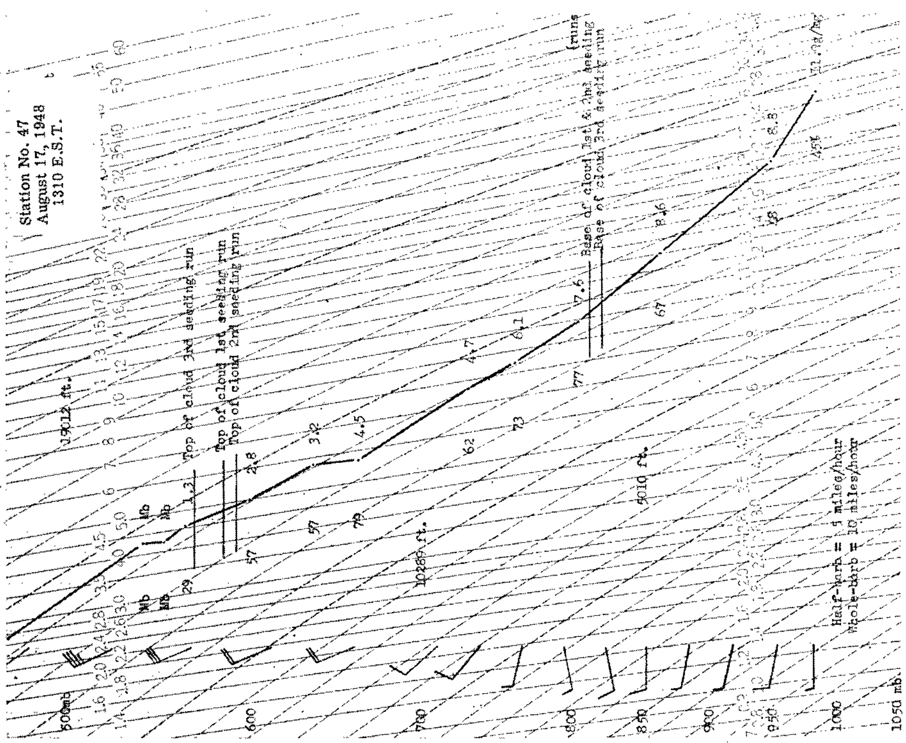

Station No. 47
July 19, 1948
1400 E.S.T.
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
Station No. 47
July 16, 1948
1400 E.S.T.
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

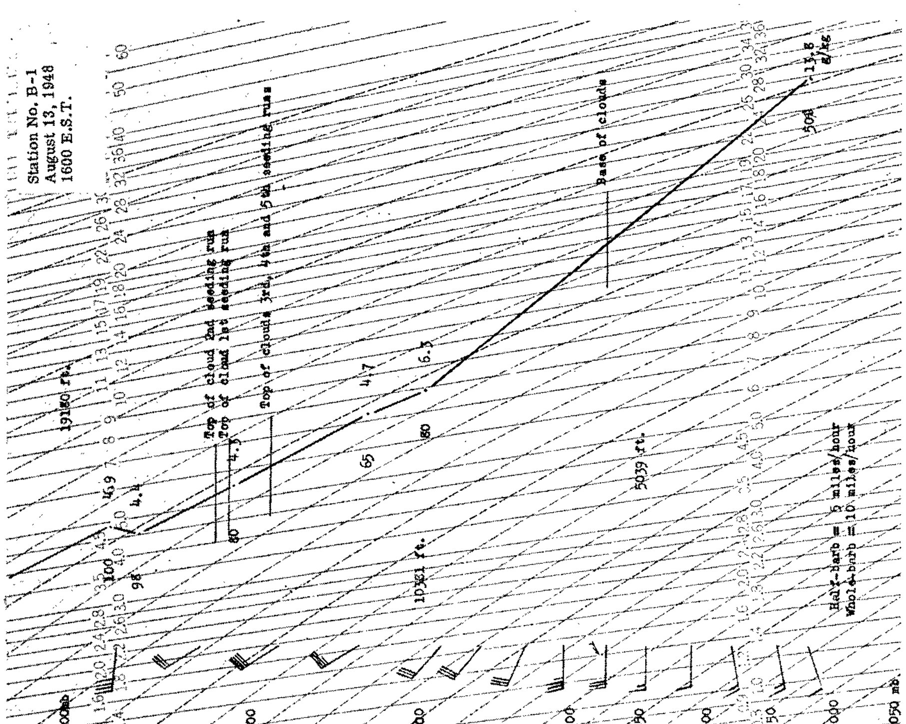

Station No. 47
July 30, 1948
1400 E.S.T.
Top of cloud 3rd seeding run
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Base of cloud 1st seeding run
Base of cloud 2nd seeding run
Base of cloud 3rd seeding run
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

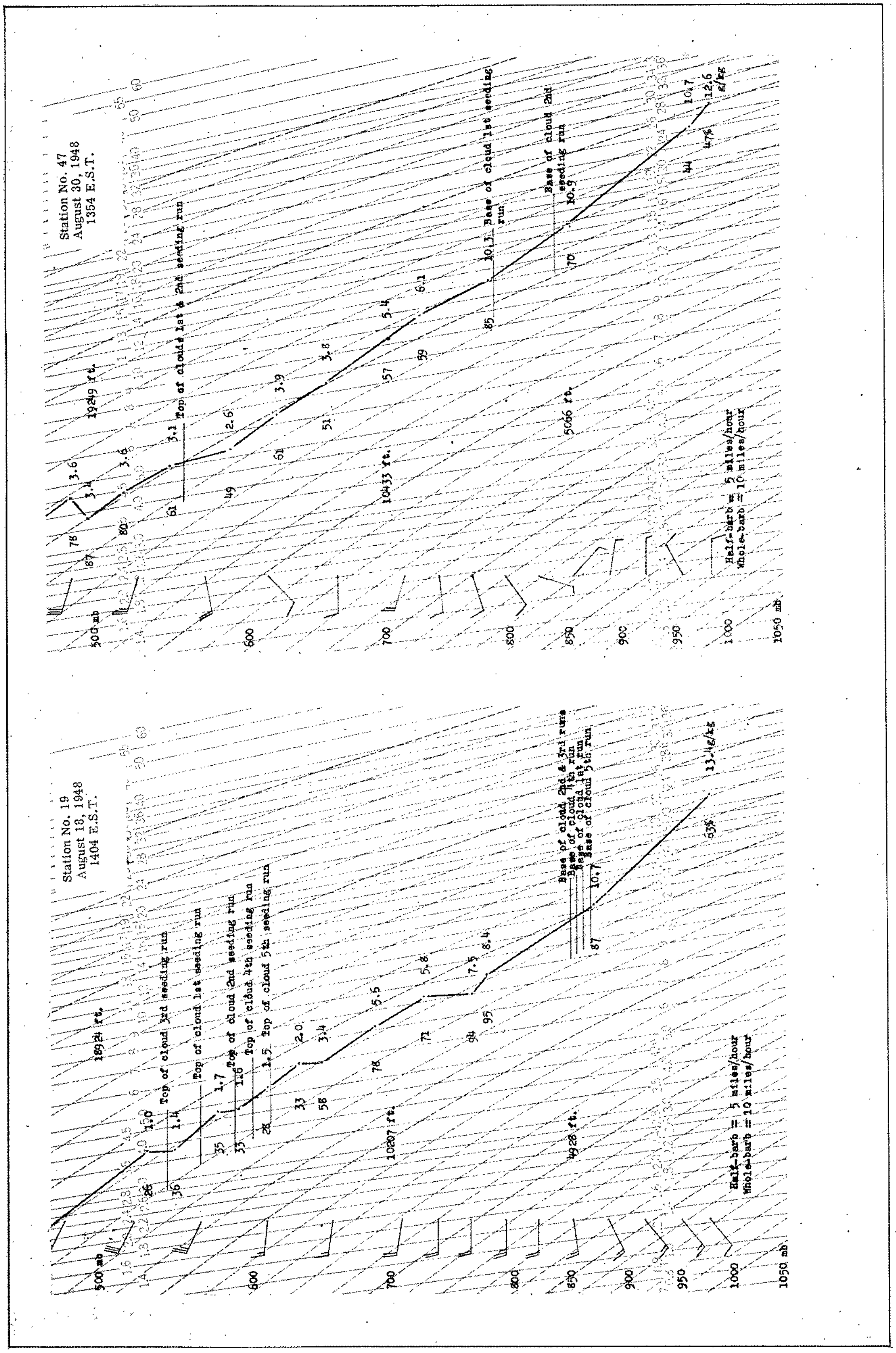

Station No. 47
July 27, 1948
1335 E.S.T.
Top of cloud 3rd seeding run
Top of cloud 4th seeding run
Top of cloud 1st & 2nd seeding runs
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour

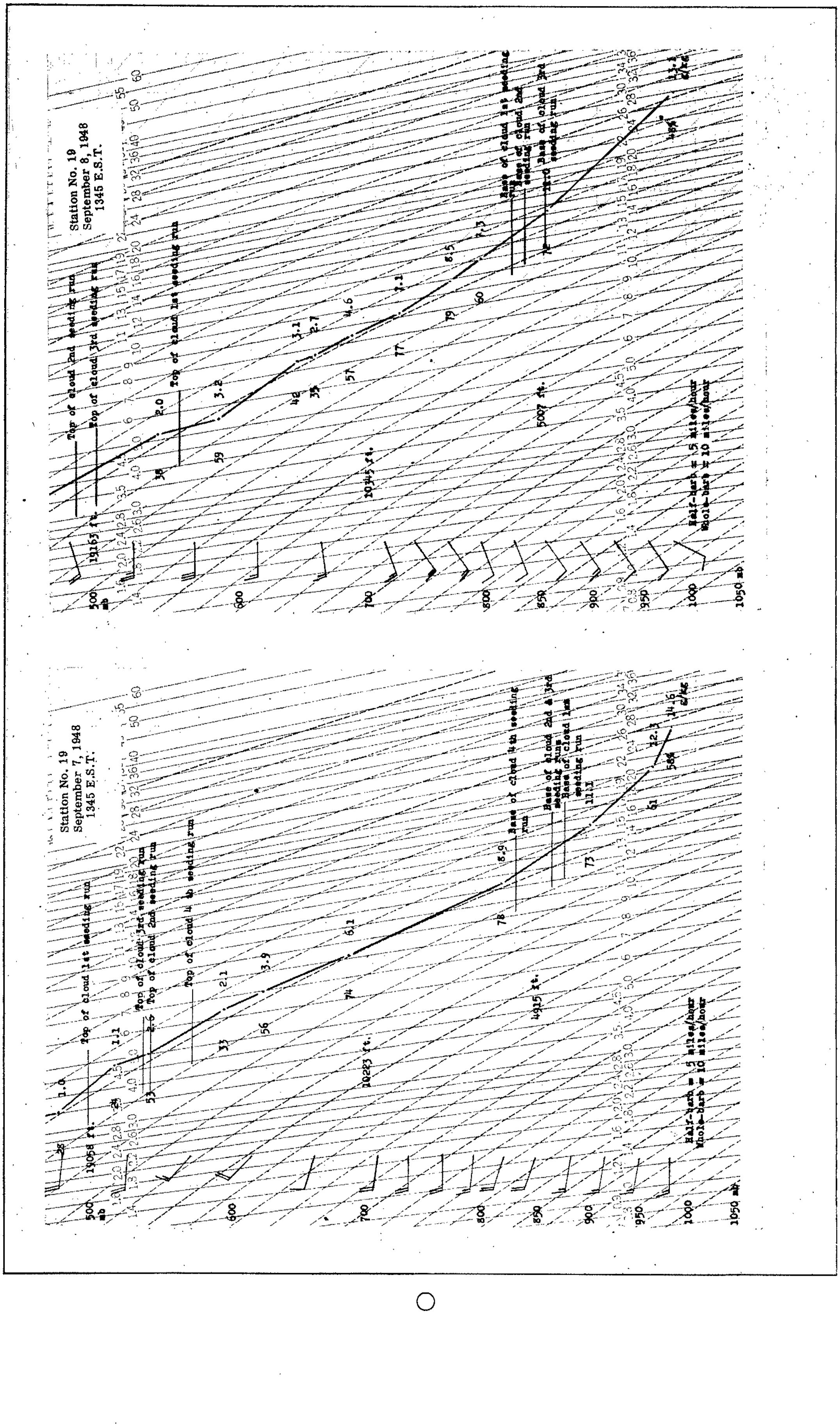

Station No. 19
August 11, 1948
1400 E.S.T.
Top of cloud 1st seeding run
Top of cloud 2nd seeding run
Top of cloud 3rd seeding run
Top of cloud 4th seeding run
Base of clouds
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour


Station No. 47
August 5, 1948
1345 E.S.T.
Top of cloud 1st seeding
Base of clouds 2nd & 3rd seeding runs
Base of cloud 1st seeding run
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour


Station No. 47
August 17, 1948
1310 E.S.T.
19012 ft.
Top of cloud 3rd seeding run
Top of cloud 1st seeding run
Top of cloud 2nd seeding run
10289 ft.
Base of cloud 1st & 2nd seeding runs
Base of cloud 3rd seeding run
5010 ft.
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
500mb
600
700
800
850
900
950
1000
1050 mb.


Station No. B-1
August 13, 1948
1600 E.S.T.
19150 ft.
Top of cloud 2nd seeding run
Top of cloud 1st seeding run
Top of clouds 3rd, 4th and 5th seeding runs
10361 ft.
Base of clouds
5039 ft.
13.8 g/kg
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
500mb
600
700
800
850
900
950
1000
1050 mb.


Station No. 47
August 30, 1948
1354 E.S.T.
Top of cloud 1st & 2nd seeding run
Base of cloud 1st seeding run
Base of cloud 2nd seeding run
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour
Station No. 19
August 18, 1948
1404 E.S.T.
Top of cloud 3rd seeding run
Top of cloud 1st seeding run
Top of cloud 2nd seeding run
Top of cloud 4th seeding run
Top of cloud 5th seeding run
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour


Station No. 19
September 7, 1948
1345 E.S.T.
Station No. 19
September 8, 1948
1345 E.S.T.
Half-barb = 5 miles/hour
Whole-barb = 10 miles/hour